WRD Resource Room JOTR

Baseline Water Quality Survey - Joshua Tree National Park

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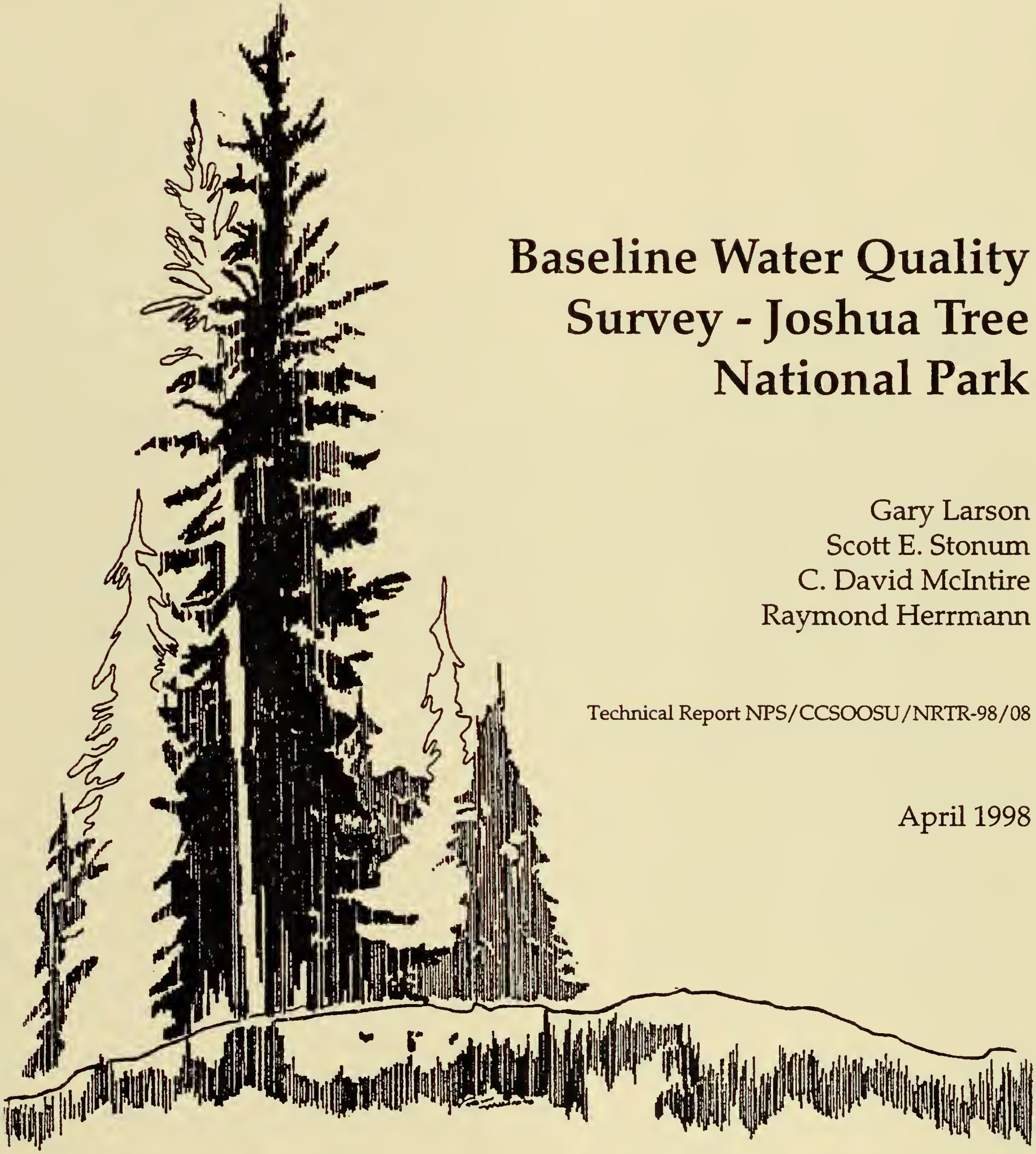

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Baseline Water Quality - Joshua Tree National Park

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ABSTRACT

Joshua Tree National Park (JOTR) is located in the Transverse Mountain Range of the California Desert. Water is one of the scarcest resources in JOTR. Annual precipitation ranges from 8.4 cm (2.4 in) in the south part of the Park to 18.0 cm (5.1 in) in Lost Horse Valley in the central portion of the park. The quantity of water at most surface water sources at JOTR is small. Many springs are ephemeral and some remain dry for years at a time. Little historic information exists about the basic water quality of the water resources of JOTR. The objectives of this baseline water quality survey include mapping of all water sources in the park, documentation of the basic water quality of selected water resources, documentation of possible changes in the depth to ground water at selected drilled wells at the Oasis of Mara, and establishment of a long-term water quality monitoring program.

A total of 266 aquatic ecosystems were identified in the park. These included 46 drilled and 49 dug wells, 32 developed (disturbed) and 54 natural tanks, and 29 developed and 56 natural springs.

The results of this study of 37 aquatic sites indicated that there was considerable diversity among six types of water resources at JOTR relative to water quality. In general, natural tanks had higher pH values and concentrations of dissolved oxygen and lower alkalinity than did the other habitat types. Reservoirs tended to have the highest water temperatures and some natural springs had the lowest temperatures. Water temperatures had a positive correlation with air temperature. Although small in sample size, a reservoir had the highest turbidity and concentrations of total Kjeldahl-N and total phosphorus relative to the values in four springs and one tank. Springs had much higher concentrations of sulfate-S than did water samples from the

tank and reservoir. The depth to ground water appeared to be increasing at six drilled wells at the Oasis of Mara.

Long-term water quality monitoring was recommended at selected sites throughout the park. This project should include basic water quality measurements and concentrations of nitrogen, phosphorus, and sulfate-S. For springs, it also was recommended that the wetted surface perimeter, distance of surface flow, and the amount of flow should be recorded. Temporal variation in the volumes of tanks also should be recorded. Park staff was encouraged to seek the advice and assistance of local, state, and federal agencies to interpret its water quality data and to assess the importance of the data to the management of the Mojave Desert.

INTRODUCTION

Joshua Tree National Park (JOTR) is located in the Transverse Mountain Range of the California Desert (Fig. 1). This Range is the only mountain system in California that trends east to west and covers broad expanses of the Mojave Desert and the Colorado Desert. Elevation of the Range spans almost 1800 m (6,000 ft) at Inspiration Peak to close to sea level in the Pinto Basin.

On October 1, 1994, Joshua Tree National Monument was redesignated as JOTR and 971.7 km^2 (237,000 acres) were added bringing the total acreage to nearly 3280.0 km^2 (800,000 acres). The added lands were transferred from the Bureau of Land Management (BLM).

JOTR was set aside to protect many diverse resources. The physical environment of air, geology, and water provided the foundation for a complex organization of plants and animals in an interconnected ecosystem. An additional level of recognition for the significance of JOTR was the designation as a International Biosphere Reserve Unit. In 1984, the Colorado and Mojave Deserts Biosphere Reserve was created to include JOTR, Death Valley National Park, Anza-Borrego State Park, and the Philip L. Boyd Deep Canyon Reserve of the University of California.

Water is one of the scarcest resources in JOTR. Annual precipitation is low (Fig. 2) and ranges from 8.4 cm (2.4 in) in the southern portion of the park to 18.0 cm (5.1 in) in Lost Horse Valley in the central portion of the park (Weir and Bader 1963). Although surface water sources occur in JOTR, the quantity of water at most sites is small. Many springs are ephemeral and some remain dry for years at a time. Little is known about the quality of park water resources.

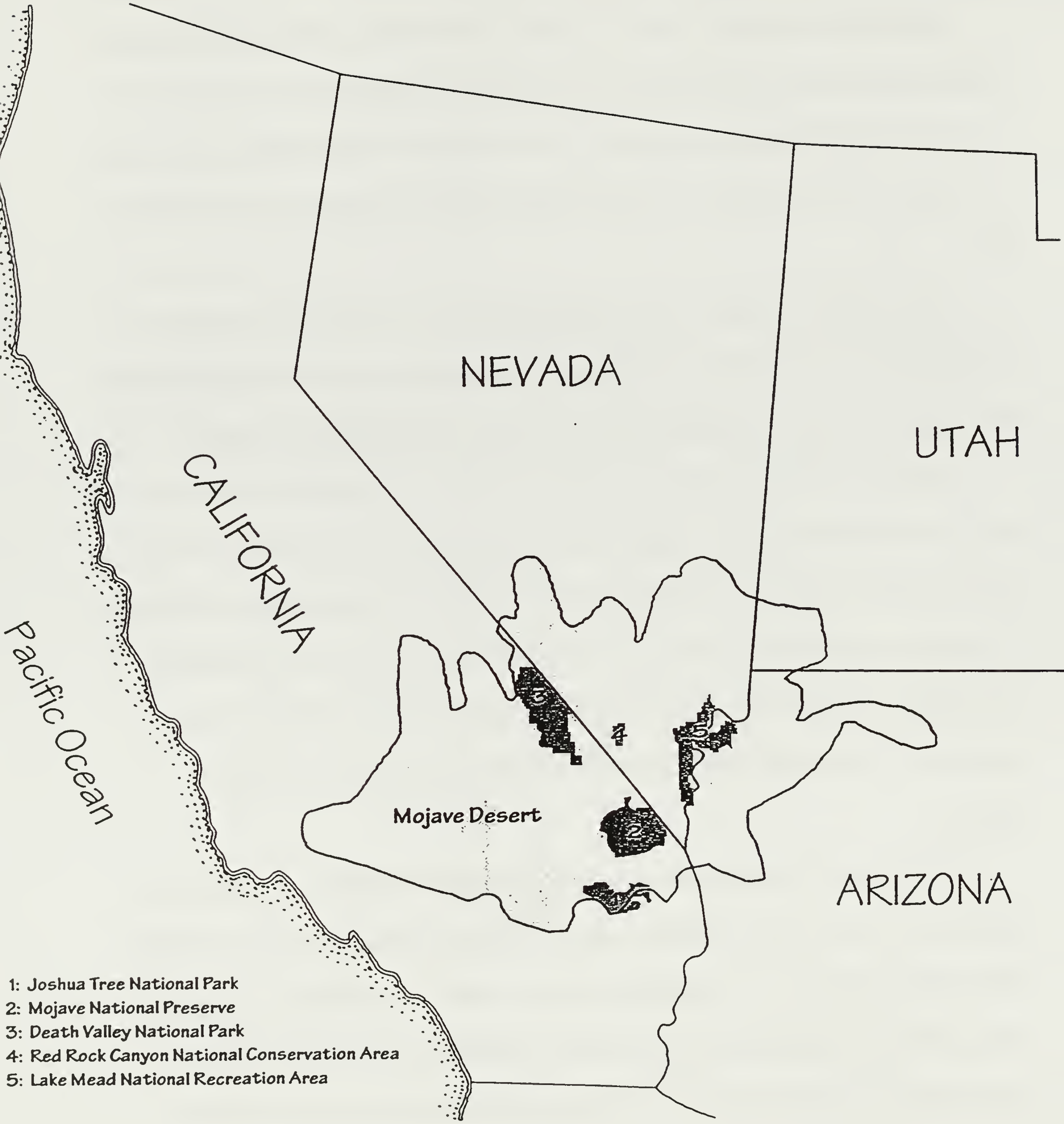

NEVADA
UTAH
CALIFORNIA
Pacific Ocean
ARIZONA
Mojave Desert
1
2
3
4
5
1: Joshua Tree National Park
2: Mojave National Preserve
3: Death Valley National Park
4: Red Rock Canyon National Conservation Area
5: Lake Mead National Recreation Area

Figure 1. Geographical location of JOTR.

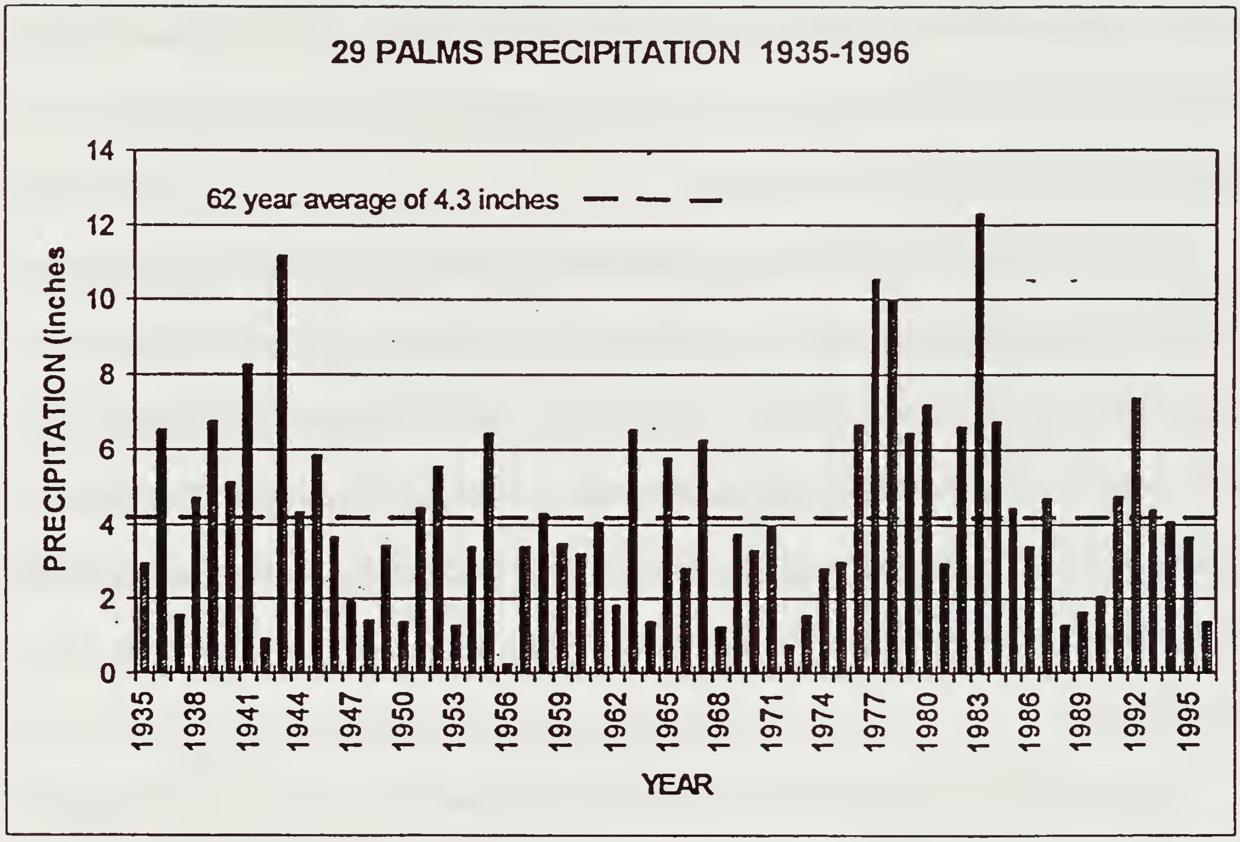


Figure 2. Temporal pattern of annual precipitation from 1935 to 1996, Joshua Tree National Park.

Located at park headquarters, the Oasis of Mara has long been a focal point for the habitation by humans of the area surrounding the community of Twentynine Palms and the park. The impressive stand of native California fan palms, rich habitat, and unique history make it a valuable resource for the park and region. The oasis is situated on an east to west trending geologic fault that aides in bringing ground water near or to the surface. The USGS established several test wells within the perimeter of the Oasis to monitor the level of the ground water between 1974 and 1982 on a sporadic basis.

Water tables have been altered by a variety of human disturbances within and outside the park. Historic mining practices used destructive methods to "improve" springs. Ground water was pumped for mining and ranching. For example, water pumped from wells during the operation of the Kaiser Steel Mine from the 1940's to 1983 at Eagle Mountain (RECON 1991) contributed to a drop in the water tables in the Pinto and Chuckwalla Basins. However, the water table in both basins recovered once the mine was closed and the excessive water use was discontinued.

At the present time, the water table in the Pinto and Chuckwalla Basins may once again be threatened owing to a proposed landfill at the abandoned Kaiser Steel Mine. Water usage is expected to be higher than those during the mining operation. The project site is within 2 kilometers of the park boundary. Also, growth of local communities surrounding the park is accelerating which require water restrictions and high prices for city water connections. This in turn powers demand for additional well-drilling by individuals and businesses outside the park.

Water is one of the limiting factors for dependent wildlife at JOTR. Several wildlife-watering pans (guzzlers) have been installed in and around the park to augment natural sources of water. During summer months when water becomes especially scarce, several species of wildlife i.e., desert bighorn sheep limit their ranges and distributions based on water availability within and near the park. Recreational interest in the park, atmospheric pollution, and development of the desert surrounding the park are increasing the potential for negative impacts to these resources. Impacts to water sources and the associated flora and fauna from these human-related activities could be severe and far reaching.

OBJECTIVES

The objectives of this baseline water-quality survey were to:

1. map the water sources in the park (format to be compatible with GIS application) with emphasis on critical sources;
2. document the basic water quality of selected water resources;
3. document possible changes in the depth to ground water at selected drilled wells at the Oasis of Mara; and
4. establish a long-term water quality monitoring program.

STUDY SITES

The delineation of water sources into several different habitat categories was necessary to define their physical appearance and historic human manipulation. Separation of the water sources into categories also allowed for independent analysis of the separate categories to determine if historic manipulation has altered any of the characteristics of the water sources. These categories also assisted in defining the nature of the water source for quick reference.

A total of 274 water source locations were thought to exist in the park. These included 56 natural springs, 29 developed springs, 54 natural tanks, 32 developed tanks, 49 dug wells, 46 drilled wells, and 8 unconfirmed sites (unpublished data, JOTR).

Many of the natural water sources in the park have been manipulated over time to increase the capacity of the sites to produce and store water for agricultural, mining or domestic use. Natural springs have been altered in many ways including channeling, piping, and being partially excavated. Natural tanks have had dams constructed at their terminal ends to increase the holding capacity of these natural reservoirs.

During this study, water samples were collected from 37 sites in the park (Fig. 3). These sites included 11 natural tanks, 1 developed tank, 8 developed springs, 1 drilled well, 14 natural springs, and 2 reservoirs (Table 1).

METHODS

Field and Laboratory

Physical and chemical variables measured included: air and water temperatures, pH, alkalinity, conductivity, dissolved oxygen, and spring discharge. Additionally, all water source locations were recorded with a geographic positioning system (GPS) unit, Rockwell PLGR. These GPS measurements were cross referenced with 7.5 minute USGS quad maps and then entered into the parks geographical information system (GIS) with attributes added to the different types of water sources.

The collection of data from the various water sources in the park provided challenges in collection techniques. Access to many of the locations required traveling long distances on various park and BLM roads followed by strenuous cross country hikes over difficult terrain. Sampling during the summer months added the stresses associated with working in extreme heat.

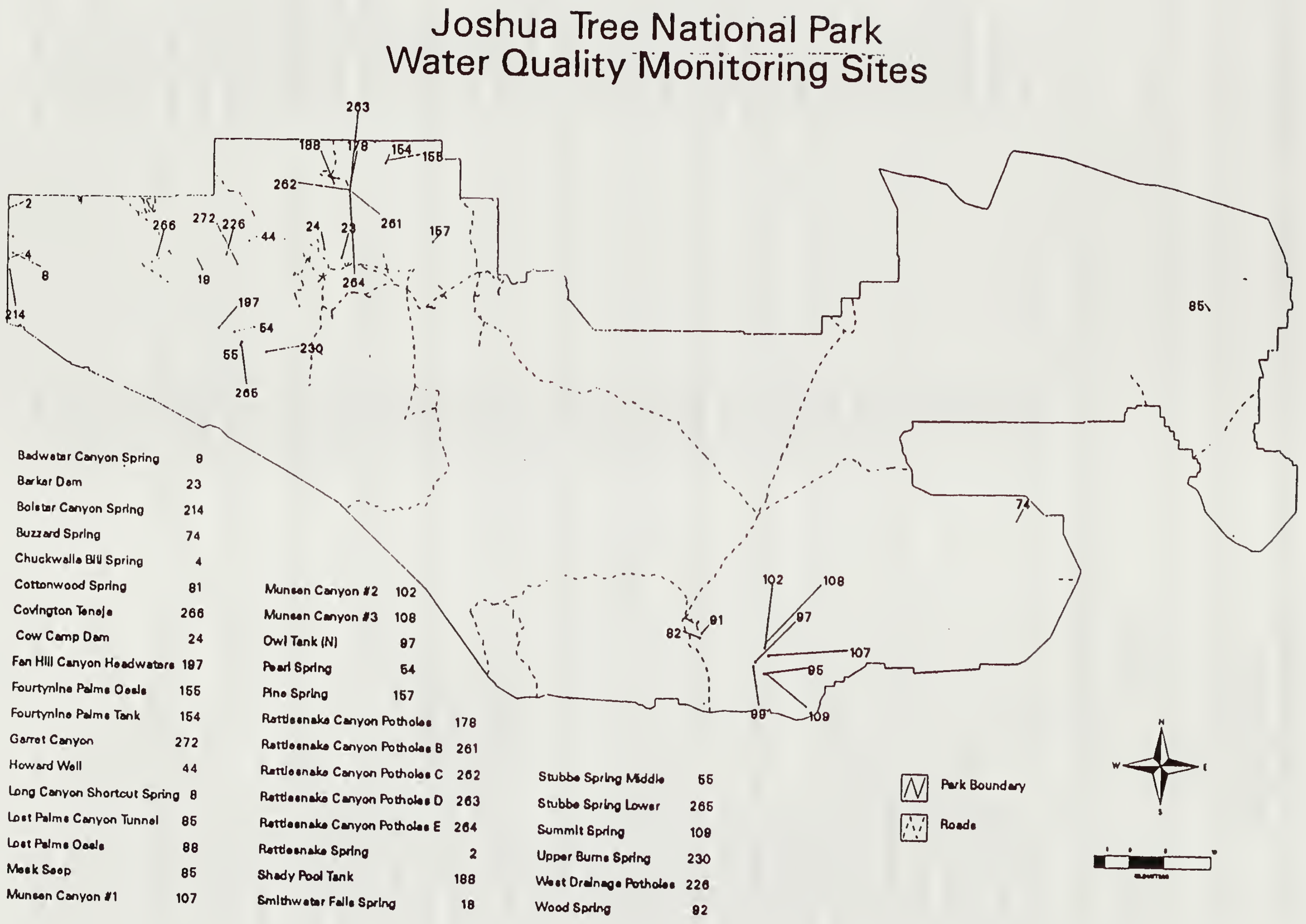


Figure 3. Locations of JOTR study sites.

Table 1. Aquatic ecosystems in Joshua Tree National Park with corresponding acronyms and habitat category.

Site Name	Acronym	Habitat
Barker Dam	BADA	reservoir
Buzzard Spring	BUSP	natural tank
Chuckwalla Bill Spring	CBSP	developed spring
Cottonwood Spring	COSP	developed spring
Covington Tenaja	COTE	natural tank
Cow Camp Dam	CCDA	reservoir
Fortynine Palms Oasis	FPOA	natural spring
Fortynine Palms Oasis Tank	FPTA	natural tank
Garret Canyon	GACA	natural spring
Howard Well	HOWE	well
Lost Palms Canyon Tunnel	LPCT	developed spring
Lost Palms Oasis	LOPA	natural spring
Meek Seep	MESE	natural spring
Munsen Canyon #1	MUC1	natural spring
Munsen Canyon #2	MUC2	natural spring
Munsen Canyon #3	MUC3	natural spring
Owl Tank (N)	OWTA	natural tank
Pearl Spring	PESP	developed spring
Pine Spring	PISP	developed spring
Rattlesnake Canyon Potholes	RSPO	natural tank
Rattlesnake Canyon Potholes B	RSPB	natural tank
Rattlesnake Canyon Potholes C	RSPC	natural tank
Rattlesnake Canyon Potholes D	RSPD	natural tank
Rattlesnake Canyon Potholes E	RSPE	natural tank
Rattlesnake Spring	RASP	developed spring
Shady Pool Tank	SPTA	developed tank
Smithwater Falls Spring	SFSP	natural spring
Stubbe Spring Middle	SSPM	developed spring
Stubbe Spring Lower	SSPL	natural spring
Summit Spring	SMSP ?	natural spring
Badwater Canyon Spring	SMSP Bas?? Bara	natural spring
Bolster Canyon Spring	BOSP	natural spring
Fan Hill Canyon Headwaters	FAHE	natural tank
Long Canyon Shortcut Spring	LCSP	natural spring
Upper Burns Spring	UBSP	natural spring
West Drainage Potholes	WDPO	natural tank
Wood Spring	WOSP	developed spring

Each site had unique characteristics that did or did not allow for all of the environmental variables to be sampled. Some sites either did not have enough water to sample at least one liter or enough water to measure any discharge.

Air and water temperatures were determined using a hand-held thermometer and recorded to within 0.5 °C. The park has collected climatological data at the Oasis of Mara since 1936 (unpublished JOTR data).

Dissolved oxygen (DO) was measured using a temperature compensated YSI Model 55, DO meter. At each sample site the altitude was entered into the meter and the membrane on the probe was checked and replaced if necessary. The probe was then placed in an area of sufficient depth to cover the probe. If enough flow was present at the springs to refresh the area around the membrane, the probe could be left in place. If spring flows were low, and at tanks and reservoirs, the probe was gently moved side to side to refresh the water in contact with the probe until the measurement stabilized. Water temperatures recorded by the DO meter were cross referenced with that of the hand-held thermometer. DO was recorded in mg/L and percent saturation.

Typically, the final on-site procedure at the springs was to determine discharge, where applicable. A temporary dam was placed in each channel using a pre-constructed dam made of plastic tarp and a drain pipe. The dam was placed in a manner so that it collected and channeled all of the surface flow through a short PVC pipe at the center of the dam. Flow through the pipe was allowed to stabilize and then measured by recording the amount of time it took to fill a 500 or 1000 ml bottle. The average from three measurements was recorded as the rate of flow in liters per minute (L/m).

For pH, alkalinity and conductivity, one liter samples were collected in the field and returned to the park laboratory for processing. Clean sample bottles were rinsed three times with water from the source being sampled. Bottles were filled, caps securely fastened, and the bottle put into a pack and kept as cold as possible. Samples were processed the same day or stored in a refrigerator overnight and then slowly returned to room temperature and processed within 24 hours. In the park laboratory, pH was determined using a Orion Model 290 meter with a temperature compensating probe. The probe was calibrated using buffers of a known pH. Prior to measuring, the pH meter was "sloped," according to the instructions in the meter manual. After sloping the meter, the probe and beaker were rinsed with sample water and 100ml of sample was poured into the beaker. The sample was placed on a magnetic stirrer and stirred at a slow speed while the probe was placed in the sample and allowed to stabilize. Conductivity was determined using a Orion Conductivity Model 126 meter. Alkalinity was determined using a HACH test kit, MDLALDT with digital titrator and sulfuric acid. Each 100 ml sample was titrated to an end point of pH 4.8 using color indicator as a guide and the pH meter. All field and laboratory data were recorded in a data base created in Microsoft Access ver. 2.0 and maintained in the JOTR Resource Management Office.

Data Analysis

The data file was organized into a matrix consisting of 101 observations of 8 chemical/physical variables from 37 sites. Variables represented in the matrix were air temperature, water temperature, pH, conductivity, alkalinity, dissolved oxygen concentration, percentage saturation (dissolved oxygen), and elevation. In addition to these variables, the data file also included a sample acronym and a habitat classification code number for each sample.

Data analysis involved the calculation of summary statistics for each variable classified by site and habitat category (Appendix I and Appendix II), a correlation and principal components analysis, a cluster analysis, a multivariate analysis of variance, and a corresponding discriminant analysis. Redundancy in the data was explored first by correlation and principal components analyses (Morrison, 1976). In this case, the eight variables were collapsed into four interpretable, independent components of variance. The cluster analysis partitioned the sample units into discrete groups based on the eight variables, independent of any exogenous classification criteria. Finally, discriminant analysis was used in relation to a multivariate analysis of variance to test for significant differences among habitat types (Morrison,1976; Pimentel, 1979). All statistical analyses except the cluster analysis were performed by various modules of the program SYSTAT (SYSTAT, Inc., Evanstan, IL). CLUSB4, a program that uses a non-hierarchical divisive algorithm (McIntire, 1973), was used to group (cluster) the sample units relative to the eight chemical/physical variables under consideration.

RESULTS

Maps

A total of 266 water resources were mapped at JOTR. These include maps of dug (49) and drilled (46) wells, natural (54) and developed (32) tanks, and natural (29) and developed (56) springs. A map delineating park watersheds also was prepared. Although these maps were not included in the report, they were sent to JOTR for future reference.

Univariate Patterns

Univariate F tests indicated that there were significant differences among habitat categories with respect to mean water temperature, pH, conductivity, alkalinity, dissolved oxygen (DO) concentration, and percentage DO saturation (Table 2). Pattern in mean water

Table 2. F statistics and associated probabilities for a univariate analysis of variance testing the hypothesis that mean values for eight chemical/physical variables were equal among five aquatic habitat categories at Joshua Tree National Park. Degrees of freedom for each test are 4 and 95, and the * symbol indicates a significant difference at the 5% level.

Variable	F	P
Air Temperature	1.568	0.189
Water Temperature	5.349	0.001*
pH	8.171	0.000*
Conductivity	5.843	0.000*
Alkalinity	39.717	0.000*
Dissolved Oxygen Concentration	9.142	0.000*
Percentage Dissolved Oxygen Saturation	6.631	0.000*
Elevation	2.347	0.060

temperature for the habitat types was similar to corresponding differences in mean air temperature (Fig. 4). The developed springs and reservoirs exhibited the two highest mean water temperatures, whereas the lowest mean water temperatures were recorded for tanks, the well, and natural springs. A plot of water temperature against air temperature for all samples (101 observations) indicated a linear relationship between these two variables (Fig. 5). Mean pH was highest (8.2 - 8.3) for samples from natural tanks and reservoirs; mean values for the other four habitat types ranged from 7.3 to 7.5 (Fig. 6). In contrast, mean conductivity was highest (924 µS cm^{-1}) in natural springs and lowest for the two samples from developed tanks (359 µS cm^{-1}). Mean alkalinity was lower in natural tanks and developed tanks (99 and 106 mg l^{-1}, respectively) than in the other habitat types, which ranged from 217 to 271 mg l^{-1} (Fig. 7). Patterns in the concentration of dissolved oxygen and percentage DO saturation were similar (Figs. 7 and 8). Mean values for these variables were highest in natural tanks, 6.5 mg l^{-1} and 60.2%, respectively, and lowest in the well (2.0 mg l^{-1} and 17.0%). Samples from reservoirs were obtained from the highest mean elevation (Fig. 8).

Data Redundancy and Components of Variance

Highest correlations among the eight chemical/physical variables (Table 3) were between dissolved oxygen concentration and percentage saturation (0.90), air and water temperature (0.83), alkalinity and conductivity (0.72), percentage saturation and pH (0.62), and dissolved oxygen concentration and pH (0.61). Alkalinity also exhibited significant but weaker correlations with pH (-0.57), dissolved oxygen concentration (-0.52), and percentage saturation (-0.53). The

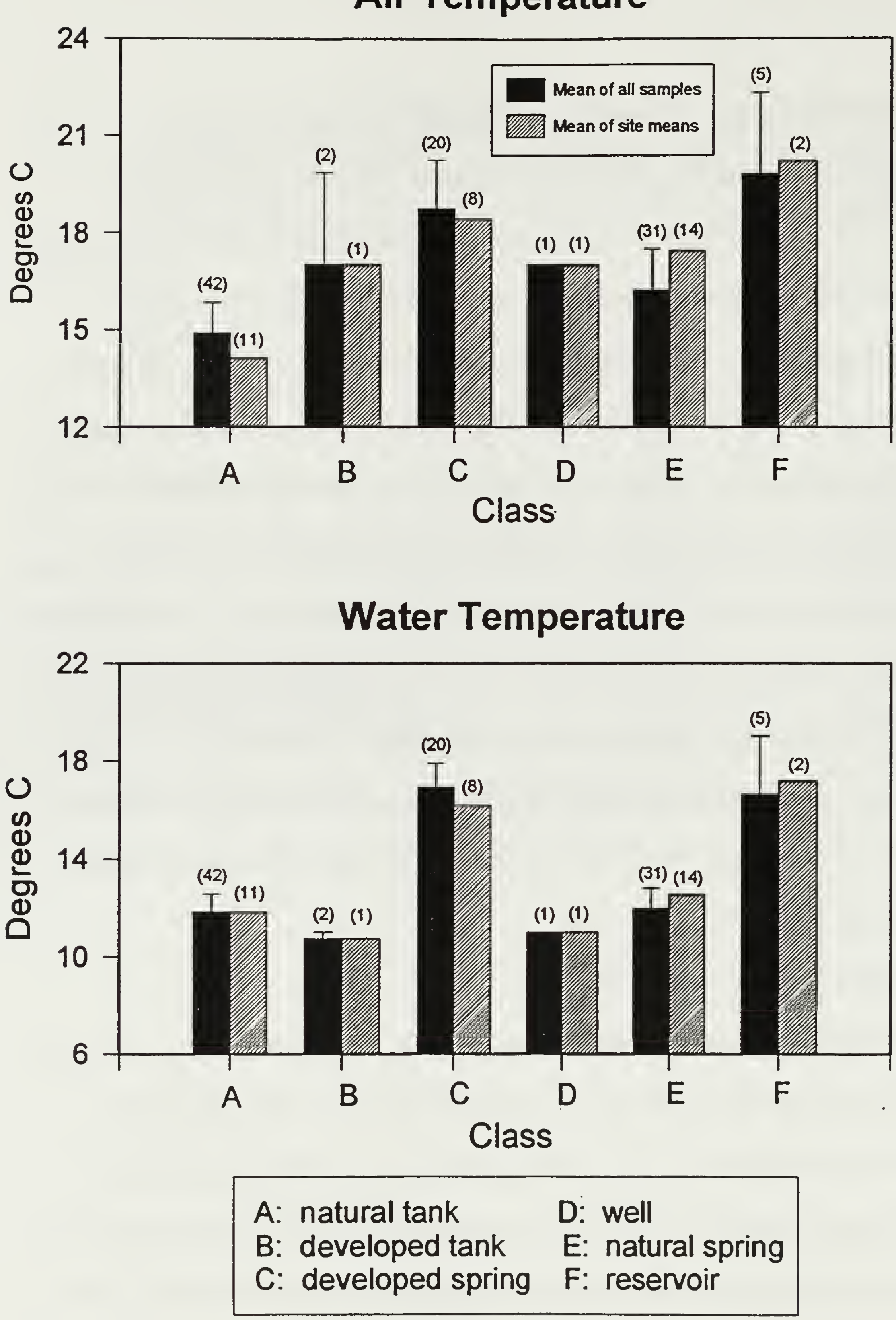


Figure 4. Mean air temperature and water temperature for samples obtained from six aquatic habitat categories in Joshua Tree National Park. Each bar also indicates the standard error of the mean and the number of samples obtained for each category.

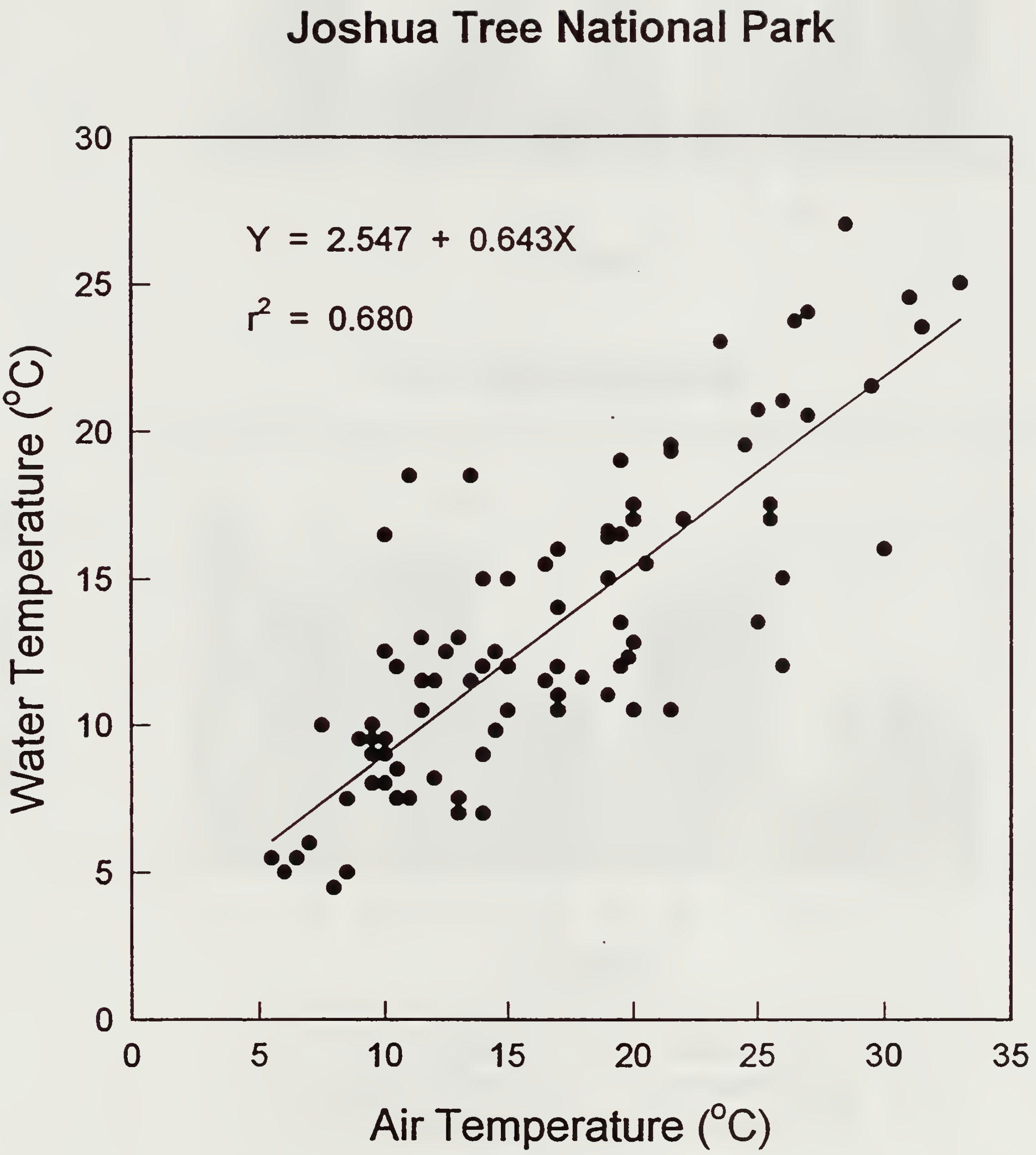
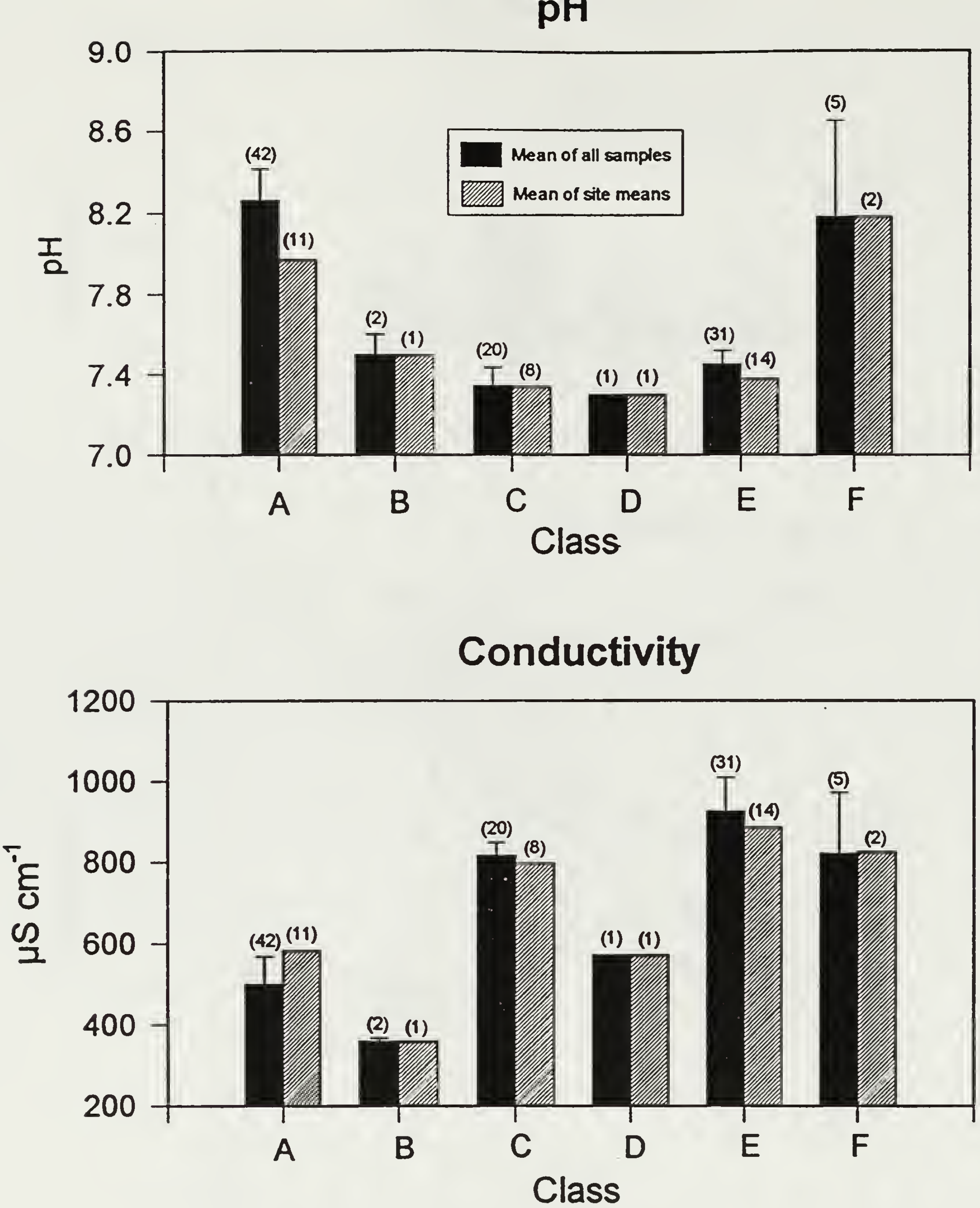


Figure 5. Relationship between air temperature and water temperature measured in 37 aquatic ecosystems in Joshua Tree National Park.



A: natural tank
B: developed tank
C: developed spring
D: well
E: natural spring
F: reservoir

Figure 6. Mean pH and conductivity for samples obtained from six aquatic habitat categories in Joshua Tree National Park. Each bar also indicates the standard error of the mean and the number of samples obtained for each category.

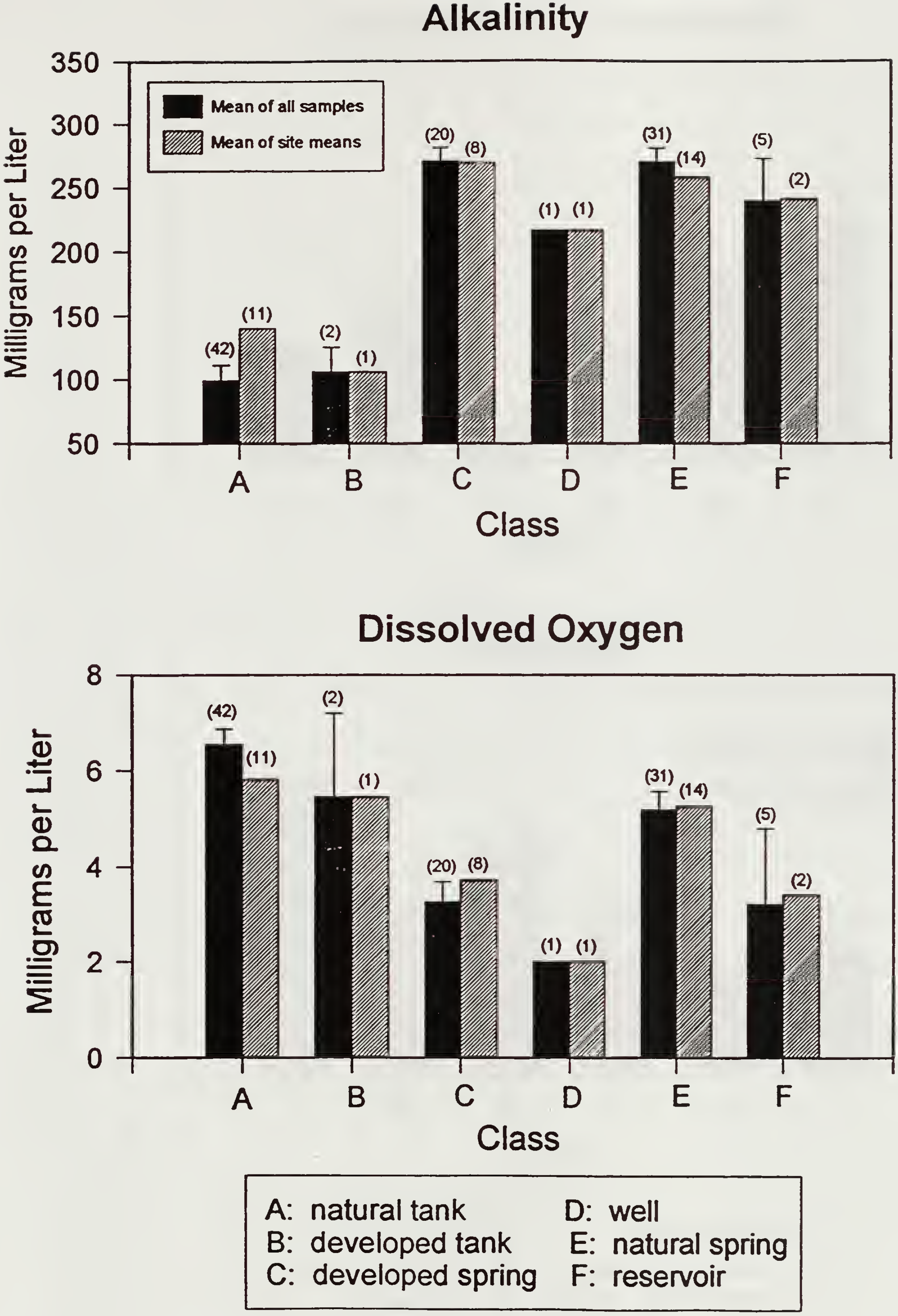
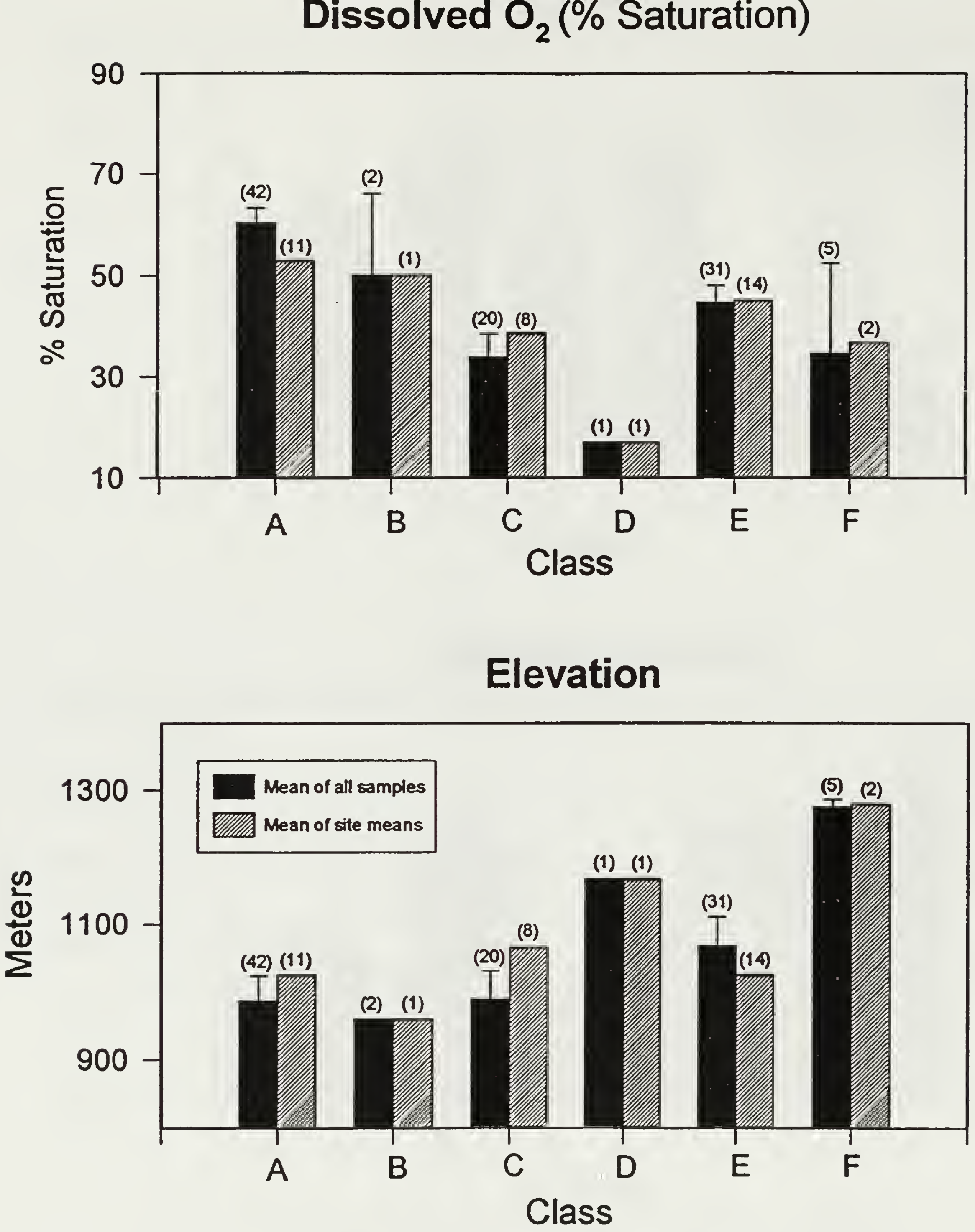


Figure 7. Mean alkalinity and concentration of dissolved oxygen for samples obtained from six aquatic habitat categories in Joshua Tree National Park. Each bar also indicates the standard error of the mean and the number of samples obtained for each category.



A: natural tank	D: well
B: developed tank	E: natural spring
C: developed spring	F: reservoir

Figure 8. Mean percentage saturation (DO) and elevation for samples obtained from six aquatic habitat categories in Joshua Tree National Park. Each bar also indicates the standard error of the mean and the number of samples obtained for each category.

Table 3. Pearson correlation coefficients comparing eight chemical/physical variables measured in 101 samples obtained from 37 aquatic ecosystems in Joshua Tree National Park. Values > 0.5 or < -0.5 are marked in bold type. The variables are air temperature (ATEMP), water temperature (WTEMP), hydrogenion activity (pH), conductivity (COND), alkalinity (ALKA), dissolved oxygen (DO), and percentage saturation dissolved oxygen (PSAT).

Variable	ATEMP	WTEMP	PH	COND	ALKA	DO	PSAT
WTEMP	**0.825**						
PH	-0.114	-0.149					
COND	0.172	0.166	-0.365				
ALKA	0.142	0.168	**-0.571**	**0.716**			
DO	-0.205	-0.345	**0.605**	-0.343	**-0.518**		
PSAT	-0.040	-0.179	**0.623**	-0.278	**-0.530**	**0.903**	
ELEV	-0.243	-0.301	-0.133	-0.238	0.105	-0.023	-0.078

correlation between pH and alkalinity or conductivity was less than between pH and the variables related to dissolved oxygen, suggesting that hydrogen ion activity is controlled, at least in part, by biological processes. The regression of pH against percentage DO saturation was significant ($F = 36.3$ with 2 and 98 d.f., $P < 0.001$) with a positive slope to the regression line (Fig. 9). This relationship indicates that the consumption of oxygen and release of carbon dioxide by microbial respiration may be associated with detectable changes in pH.

Although the data file included eight chemical/physical variables, it was possible to collapse 89.4% of this information into four statistically independent variables by principal components analysis. A preliminary analysis indicated that the maximum loading for each variable occurred in one of the first four principal components. These components were altered by varimax rotation, a transformation that maximized the loadings in a way that improved interpretation (Table 4).

The first principal component (rotated), which accounts for 30.8% of the variance, has high negative loadings for pH and the two variables associated with dissolved oxygen (Table 4). Therefore, sites and habitat types with high scores for this component would be expected to have a relatively low pH and concentrations of dissolved oxygen, and perhaps more heterotrophic microbial activity than locations with higher scores. The second principal component, with high positive loadings for both and air and water temperature, accounted for 23.2% of the variance and is clearly an expression of the variance and covariance of the two temperature variables. Conductivity and alkalinity are expressed by the third component, which represents 21.9% of the variance; whereas the fourth component, with only 13.5% of the variance, has a high loading for elevation.

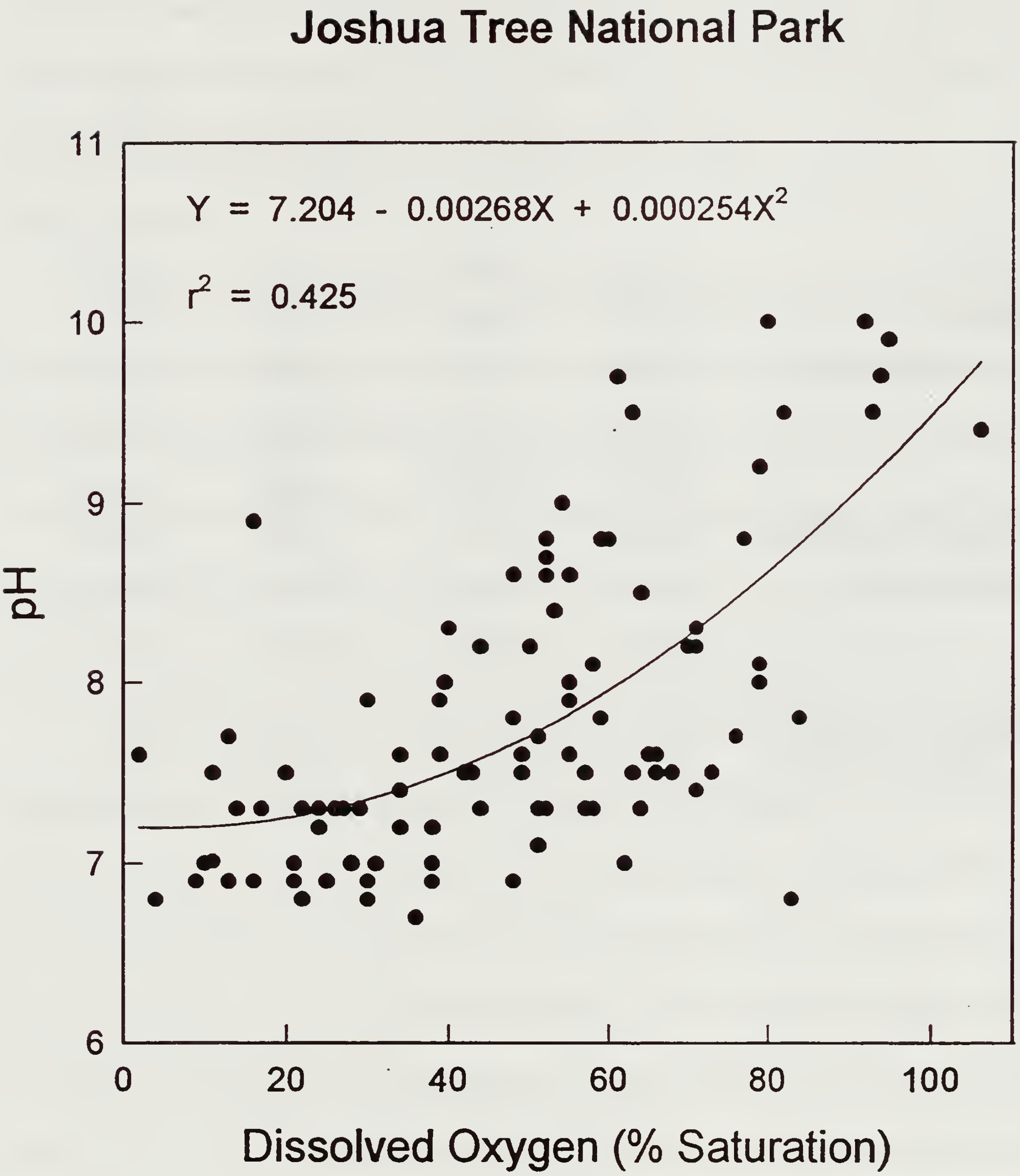


Figure 9. Relationship between percentage saturation (DO) and pH measured in 37 aquatic ecosystems in Joshua Tree National Park.

Table 4. Factor loadings derived from the varimax rotation of the first four principal components associated with the analysis of eight chemical/physical variables measured in 101 samples from 37 aquatic ecosystems in Joshua Tree National Park. The highest loading for each variable is indicated by bold type.

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Air Temperature	0.012	**0.956**	0.097	0.059
Water Temperature	0.180	**0.926**	0.038	0.162
Hydrogen Ion Activity (pH)	**-0.685**	-0.071	-0.392	0.205
Conductivity	0.140	0.070	**0.918**	0.232
Alkalinity	0.405	0.085	**0.831**	-0.169
Dissolved Oxygen Concentration	**-0.926**	-0.184	-0.168	-0.033
Percentage DO Saturation	**-0.957**	-0.004	-0.145	0.004
Elevation	0.068	-0.181	-0.060	**-0.962**
% of Total Variance Explained	30.80	23.20	21.89	13.52

In summary, the principal components analysis, because of redundancy in the data set, allowed a more parsimonious representation of variation in this particular set of variables. Moreover, the analysis indicates that it may be possible to use only three, or possibly four, variables instead of the original eight to help explain pattern in a set of corresponding response variables (e.g., density of organisms and related biological data).

Site Classification

A cluster analysis classified 101 samples from 37 aquatic ecosystems into discrete groups relative to the eight chemical/physical variables. The clustering algorithm was a non-hierarchical, divisive procedure that systematically divided the observations into an arbitrary number of groups specified by the user. In this case, a five-cluster structure was considered the most interpretable configuration, as further divisions generated some groups with just one sample. Cluster assignments for individual samples are tabulated in Appendix III.

Cluster 1 (Appendix III) consisted primarily of samples from natural tanks (Table 5). Samples in this cluster had the highest mean pH, a relatively low mean conductivity and alkalinity, and the next to the highest mean concentration of dissolved oxygen (Table 6); mean water temperature for this group was similar to the corresponding means for clusters 2 and 5. Cluster 2 (Appendix III) was composed of samples from all six habitat categories, and cluster 3 had a similar relative composition of samples as cluster 2 (Table 5). Clusters 2 and 3 separated mostly on the basis of air and water temperature, and to a lesser degree, elevation, but have similar values for mean pH, conductivity, alkalinity, and concentration of dissolved oxygen (Table 6). Clusters 2 and 3 also indicate that there is considerable overlap among the six habitat categories with respect to this particular set of chemical/physical variables. The two small

Table 5. The number of samples from six habitat categories classified into five clusters by a cluster analysis of eight chemical/physical variables measured for 37 aquatic ecosystems in Joshua Tree National Park. Distance values are the mean euclidean distances between a cluster centroid and the centroids of the four neighboring clusters.

Habitat Type	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Total
Natural Tank	26	5	2	4	5	42
Developed Tank	1	1	-	-	-	2
Developed Spring	1	11	8	-	-	20
Well	-	1	-	-	-	1
Natural Spring	2	13	8	2	6	31
Reservoir	1	3	1	-	-	5
Total	31	34	19	6	11	101
Mean Distance	12.6	11.2	13.8	19.8	15.6	-

Table 6. Mean values of eight chemical/physical variables for each of the five clusters determined by an analysis of data from 37 aquatic ecosystems in Joshua Tree National Park. The variables are air temperature (ATEMP), water temperature (WTEMP), hydrogen ion activity (PH), conductivity (COND), alkalinity (ALKA), dissolved oxygen (DO), percentage saturation dissolved oxygen (DOSAT), and elevation (ELEV). See Appendix III and Table 5 for cluster assignments.

Cluster	Size	ATEMP (°C)	WTEMP (°C)	PH	COND (μS cm^{-1})	ALKA (mg l^{-1})	DO (mg l^{-1})	DOSAT (%)	ELEV (m)
1	31	13.8	11.2	8.6	337	84	7.1	65	947
2	34	13.9	12.0	7.3	796	264	3.3	30	1143
3	19	25.7	19.7	7.5	710	232	4.2	41	971
4	6	8.8	6.7	7.6	420	130	8.6	74	1532
5	11	19.2	13.6	7.7	1619	257	5.9	60	720

clusters (4 and 5) consist of samples only from natural tanks and natural springs (Appendix III, Table 5). Cluster 4 was characterized by the lowest mean air and water temperature, a relatively low mean conductivity and alkalinity, and the highest mean elevation and mean concentration of dissolved oxygen; samples in cluster 5 had the highest mean conductivity and lowest mean elevation.

The mean euclidian distance between cluster centroids was highest for cluster 4, in part because of its relatively high mean conductivity (Tables 5 and 6). The two most similar clusters were 2 and 3 with a standardized distance (6.7) considerably below means listed in Table 5. Highest distance values between centroids of individual pairs of clusters were between cluster 3 and 4 (25.9) and between cluster 4 and 5 (27.6).

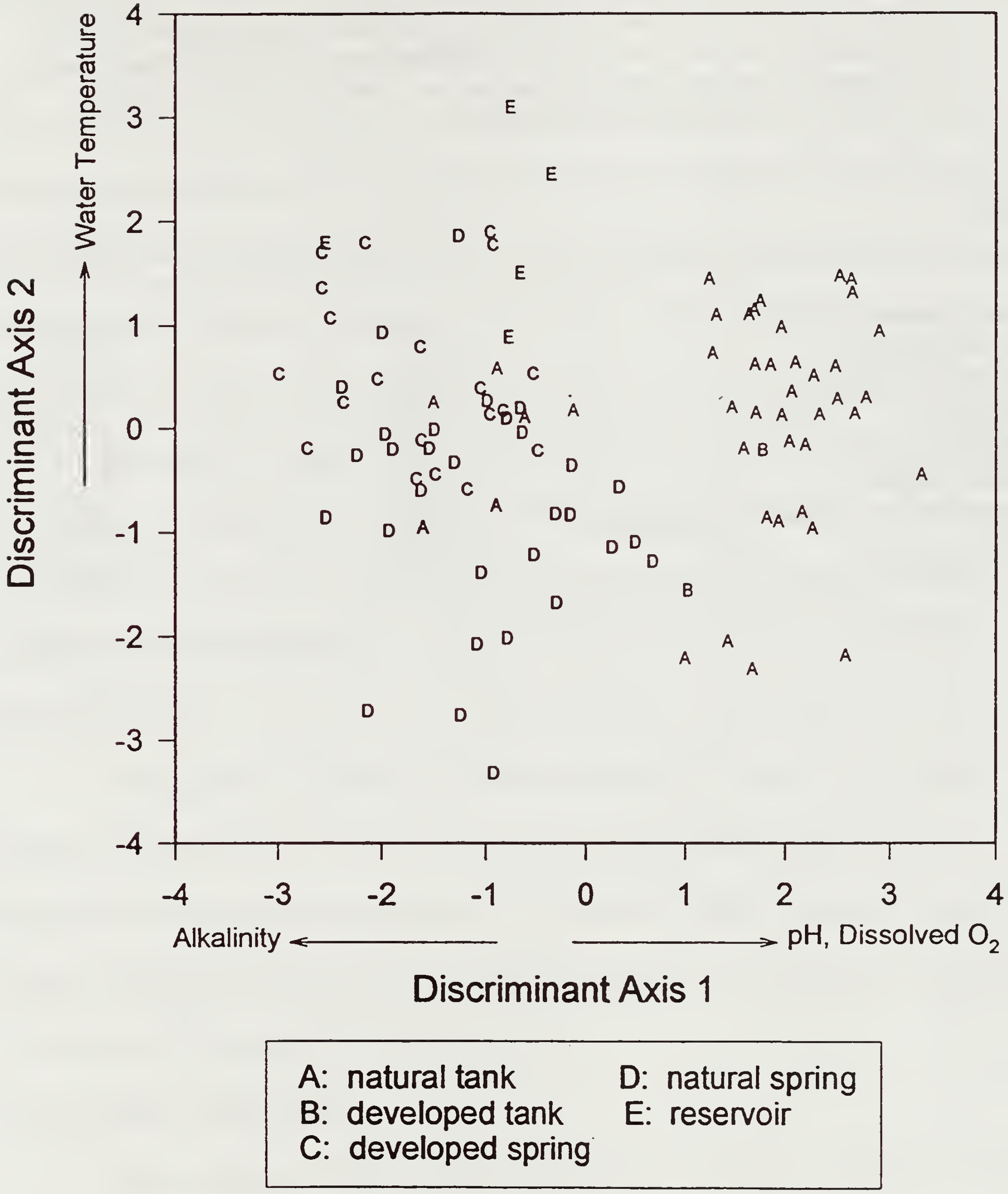
Evaluation of Habitat Categories

The cluster analysis assigned sample units to groups based only on standardized values of the eight chemical/physical variables, and without the consideration of extrinsic classification criteria (e.g., membership in a habitat category). It was also of interest to investigate the degree of similarity or dissimilarity among groups of samples classified on the basis of habitat category. For this analysis, samples were assigned to one of five groups based on the type of habitat: natural tanks, developed tanks, developed springs, natural springs, and reservoirs. There was only one sample unit from a well (Howard Well), so this habitat category was eliminated from the analysis. Differences among the groups, relative to the eight chemical/physical variables, were investigated by a multivariate analysis of variance (Morrison, 1976) and a canonical analysis of discriminance (Pimentel, 1979).

A multivariate analysis of variance indicated that there were significant differences among the centroids for the five habitat categories (F = 6.4 with 32 and 326 d.f., $P < 0.01$). In addition, the discriminant analysis indicated that 73% of the sample units were classified into the correct habitat category, and that all five sample units from the reservoirs and the two sample units from a developed tank were classified correctly (Table 7). The greatest percentage of misclassifications were found for natural springs (35.5%), followed by natural tanks (28.6%), and developed springs (20.0%). A plot of the first and second canonical axes from the discriminant analysis revealed that most sample units from natural tanks were clustered together on the right side of the graph (Fig. 10). Moreover, many samples from natural springs were located towards the left and lower left of the plot, and the five sample units from the reservoirs were near the top of the graph, indicating some similarities within each group. This analysis also revealed considerable similarity among samples from developed springs and some of the natural springs. Correlations between the first two discriminant axes and the eight chemical/physical variables indicated that the first discriminant axis expressed a contrast between alkalinity and conductivity and the pattern in pH and dissolved oxygen concentration (Table 8). In other words, natural tanks with relatively high scores on this axis tended to have higher pH values and concentrations of dissolved oxygen and lower alkalinity than did the other habitat types. This pattern is consistent with the univariate analysis presented earlier. The second discriminant axis was primarily an expression of water temperature. At the extremes of this axis, reservoirs tended to have relatively high water temperatures and some of the natural springs were associated with relatively low water temperatures.

Table 7. Classification table for the discriminant analysis of eight chemical/physical variables measured at 36 aquatic ecosystems in Joshua Tree National Park. The habitat groups evaluated by the analysis are natural tanks (NT), developed tanks (DT), developed springs (DS), natural springs (NS), and reservoirs (RV). The actual grouping is represented by the rows in the matrix and the predicted grouping is indicated by the columns in the matrix. The diagonal values in bold type indicate the number of sample units that were classified correctly; whereas the off-diagonal values represent the misclassifications.

Ecosystem Type	NT	DT	DS	NS	RV	Actual Total
NT	**30**	7	2	3	0	42
DT	0	**2**	0	0	0	2
DS	0	0	**16**	3	1	20
NS	0	2	6	**20**	3	31
RV	0	0	0	0	**5**	5
Predicted Total	30	11	24	26	9	100



Joshua Tree National Park

Discriminant Analysis of Chemical/Physical Data

Figure 10. Plot of the first two canonical axes derived from a discriminant analysis of 100 samples of eight chemical/physical variables obtained from 37 aquatic ecosystems in Joshua Tree National Park. Sample units were pooled by five habitat categories: natural tank (A), developed tank (B), developed spring (C), natural spring (D), and reservoir (E).

Table 8. Pearson correlation coefficients indicating relationships between the scores for the first two discriminant axes and eight chemical/physical variables measured at 36 sites in aquatic ecosystems at Joshua Tree National Park. The discriminant analysis was designed to evaluate differences among five habitat categories. Loadings greater than 0.5 are indicated in bold type.

Variable	Axis 1	Axis 2
Air Temperature	-0.245	0.226
Water Temperature	-0.332	**0.535**
Hydrogen ion activity (pH)	**0.553**	0.296
Conductivity	**-0.501**	-0.180
Alkalinity	**-0.944**	-0.179
Dissolved Oxygen	**0.567**	-0.378
Percentage Saturation Dissolved Oxygen	**0.542**	-0.188
Elevation	-0.158	0.122

Turbidity and Nutrients

Four springs, one tank, and one reservoir were sampled for turbidity and nutrients during 1996 and 1997. Relative to the available data, TKN ranged from 0.4 to 0.8 mg/L in the springs, whereas the tank (RSPC) ranged from 1.5 - 1.6 mg/L and the reservoir (CCDA) had a concentration of 21.0 mg/L (Table 9). Nitrate-N ranged from below detection limits (BDL) to 3.8 mg/l, the highest concentration occurring in a sample from BUSP. Ammonia-N ranged from BDL to 0.3 mg/L and total phosphorus was mostly at BDL with the exception of 1.9 mg/L in CCDA. Orthophosphate-P was at BDL in all sites, with the exception of one sample from RSPC (0.11 mg/L). The springs ranged from 29.0 to 780.0 mg/L sulfate-S. The tank and reservoir ranged from 10.0 to 18.0 mg/L sulfate-S. Turbidity was low at all sites with the exception of the sample from CCDA (110.0 NTU).

Spring Discharge

Discharge from the springs was usually less than 3.0 L/m (Table 10). The single measurement at GACA in May 1995 was 5.3 L/m. Discharge of SSPM was 7.2 L/m in November, 1995, but discharge decreased to 2.2 L/m by April, 1996. The highest discharge recorded during the study was 29.4 L/m at SFSP in October, 1995. The discharge of this spring was 15.0 L/m in March and 7.0 L/m in July, 1996.

Oasis of Mara Ground Water

The sporadic ground-water level measurements recorded between 1974 and 1982 and monthly measurements recorded from 1994 through 1996 at the Oasis of Mara during the course of this study indicate that the depth to water has increased in the six wells tested at the Oasis (Fig. 11). During this study, depth to ground water throughout the Oasis varied from about

Table 9. Concentration of total Kjeldahl-N (TKN), nitrate-N (N03-N), ammonia (NH3-N), totalphosphorus (TP), orthophosphate-P (P04-P), sulfate (S04-S), and turbidity (TURB). Turbidity expressed at NTU, nutrients as mg/L. SFSP, BOSP, BUSP, and SSPL are springs. RSPC is a tank and CCDA is a reservoir. See Table 1 for site acronyms.

Site	Date	TKN	NO3-N	NH3-N	TP	PO4-P	SO4-S	TURB
SFSP	110696	0.5	BDL*	BDL	BDL	BDL	110.0	5.8
	031297	0.5	BDL	0.1	0.05	BDL	95.0	6.4
BOSP	112096	0.8	0.3	0.1	BDL	BDL	780.0	0.3
	031097	0.7	0.4	0.3	BDL	BDL	620.0	0.6
BUSP	110396	0.4	1.2	0.2	BDL	BDL	290.0	0.4
	031097	0.4	3.8	0.3	BDL	BDL	210.0	0.4
SSPL	031397	0.4	BDL	BDL	0.08	BDL	29.0	8.7
RSPC	103196	1.6	1.6	0.2	BDL	0.11	12.0	1.5
	030997	1.5	0.8	0.1	BDL	BDL	10.0	1.8
CCDA	112696	21.0	0.7	0.3	1.9	BDL	18.0	110.0

* Below detection limits

Table 10. Discharge (L/minute) of selected JOTR springs.

Spring	Month	Day	Year	Discharge
BOSP	11	6	95	2.1
CBSP	10	26	95	2.3
	4	17	96	2.3
	5	15	96	1.5
	7	17	96	1.3
GACA	5	1	96	5.3
LCSP	10	26	95	0.5
	4	17	96	1.9
PESP	6	20	96	3.5
RASP	10	30	95	0.9
	4	16	96	0.6
SPTA	5	14	96	1.2
SFSP	10	27	95	29.4
	3	21	96	15.0
	7	9	96	7.0
SSPM	11	16	95	7.2
	4	24	96	2.2
SSPL	11	16	95	0.6

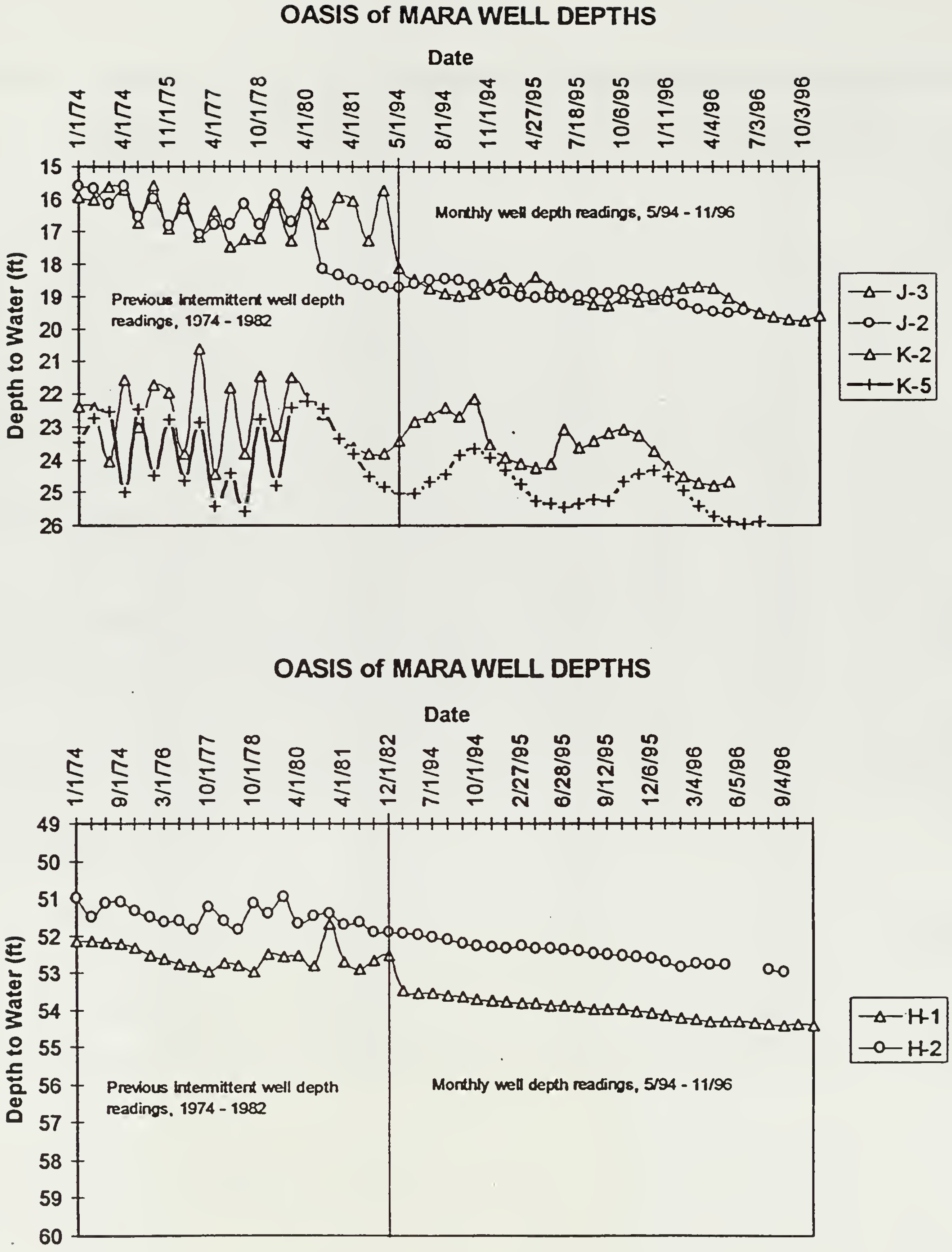


Figure 11. Temporal changes of ground water depths at six wells at the Oasis of Mora, Joshua Tree National Park.

5.8 m (19 ft) at the shallowest point to 16.5 m (54 ft) at the north side of the fault.

New Water Resources

During the course of this study three previously undocumented water sources were discovered. Garret Canyon, Milner Seep, and Covington Teneja were not described in any of the literature reviewed or present on any of the maps for the park. The sites are reliable water sources and the site now referred to as Garret Canyon had more than 800 m (0.5 mile) of water flowing at the surface. Additional findings during field sampling included two previously undocumented prehistoric cultural sites.

Wildlife Observations

Numerous wildlife observations were recorded throughout the field sampling. Obviously these were important water sources to the diverse range of wildlife species present in the park. For example, mule deer, desert bighorn sheep, coyote, and many bird species relied heavily on the presence of water in the desert environment of JOTR. Impacts to water sources from domestic horse use and visitor use were observed at several locations that could result in long-term negative impacts to these resources and the animals that depend on them.

DISCUSSION

The results of this study indicated that there is considerable diversity among the water resources of JOTR relative to water quality. In general, natural tanks had higher pH values and concentrations of dissolved oxygen and lower alkalinity than did the other habitat types. Reservoirs tended to have the highest water temperatures and some natural springs had the lowest temperatures. Water temperatures had a positive correlation with air temperature. Although small in sample size, a reservoir had the highest turbidity and concentrations of total

Kjeldahl-N and total phosphorus relative to the values in four springs and one tank. Springs had much higher concentrations of sulfate-S than did water samples from the tank and reservoir.

The depth to ground water at six wells at the Oasis of Mara is increasing, perhaps in response to declining precipitation in recent years. According to Frazier 1977 and Cornett (1994), ground water levels of not greater than 5.5 m to 6.1 m (18 to 20 ft) below the surface of the ground are required to support native fan palm populations. Ground water levels deeper than this would facilitate the need for supplemental watering. Existing ground water levels through most of this Oasis are not sufficient to support the continued health of the fan palms and future recruitment of fan palm seedlings. Currently, park staff supply supplemental water in the central part of the Oasis. If the documented downward trend in water level persists, the remaining areas may no longer support the palms and other vegetation associated with the Oasis.

The following recommendations are provided for additional water quality monitoring at JOTR:

(1) Initiate a long-term water quality monitoring program. The information gathered can be used to assess changes caused by natural variations of the environment and variation caused by human-related activities.

(2) The water quality data base (volume [see below], temperature, turbidity, salinity, pH, alkalinity, conductivity, and dissolved oxygen) for each study site needs to be expanded to document "normal average conditions" and the expected range of variability of each variable. Three samples should be taken each season (when possible) and the results averaged. These average values should be added to the existing data base and new averages calculated for each month by site. This effort should continue until the variance

(expressed as 1 standard deviation) around the average of each variable at each site is reduced. Once the data base is large enough to document normal average conditions, sampling can be reduced to selected seasons each year or seasonal samples could be taken every second or third year. Water samples for nutrient and turbidity analyses should continue to be collected. Owing to the costs of such analyses, these should taken once each season and the results added to the data base as discussed above.

(3) Based on the present study, the water quality monitoring study should continue at the following sites that provide, in most cases, a range of water qualities for each habitat type--Natural tanks [BUSP, WDPO, RSPC, and RSPO]; Developed tank [SPTA]; Developed spring [CBSP, COSP, and LPCT]; Natural spring [SSPL, RASP, and FPOA]; and Reservoir [BADA and CCDA].

(4) The wetted surface perimeter and distance of surface flow from each spring should be recorded on each sampling date. To the extent possible, water flow should continue to be recorded, either as liters per minute or some measurement of stage height near each spring source. In addition to air and water temperature measurements on each sampling date, temperature loggers should be installed at the source of each spring selected for long-term monitoring to document daily, seasonal, and annual variations of water temperature.

(5) The landscape has been shaped by periodic storm (flood) events. Evaluating the influences of flood events on water quality will require separate studies that should include repeated samplings before, during, and after floods.

(6) Water samples should continue to be collected and analyzed using consistent techniques and descriptions of techniques should be cross referenced to the numerical data. The location of each sampling site should be documented for future investigations.

(7) For the ephemeral study sites, annual dates of drying and dates of recharge should be documented.

(8) Tank volumes should be determined on each sampling date. The techniques required to obtain this information are described by Girdner and Larson (1995).

(9) Continued monthly monitoring of the wells at the Oasis of Mara is recommended and investigations into the possible causes of the drop in the ground water should be initiated. Although the declines may be in response to low precipitation in recent years, municipal deep-water wells in the vicinity of the Oasis and other wells along the fault could be contributing to the documented declines. Additional watering may be warranted in the western portion of the Oasis where the ground water levels appear to be below critical levels for the palms.

(10) Impacts to water sources from human-related activities were observed at several locations that could result in long-term negative impacts to these resources and the animals that depend on them. Continued efforts to limit these types of disturbances are highly recommended.

(11) Continue to record annual precipitation at park headquarters. Furthermore, the chemistry of the precipitation should be determined.

(12) JOTR is encouraged to distribute the water quality data base to local, state, and federal agencies. Furthermore, JOTR is encouraged to seek the advice and assistance from these agencies to interpret its water quality data and to assess the importance of the data to the management of the Mojave Desert.

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Appendix I. Mean (MEAN), maximum (MAX), minimum (MIN), standard deviation (STD. DEV.), and standard error of the mean (STD. ERROR) for eight chemical/physical variables measured at 37 sites in Joshua Tree National Park. The variables are air temperature (ATEMP), water temperature (WTEMP), hydrogen ion activity (PH), conductivity (COND), alkalinity (ALKA), dissolved oxygen concentration (DO), percentage dissolved oxygen saturation (DOSAT), and elevation (ELEV). The temperature variables are expressed as °C; conductivity as $\mu S\ cm^{-1}$; alkalinity and dissolved oxygen concentration as $mg\ l^{-1}$, and elevation as meters.

Site Name: Badwater Canyon Spring

Number of samples: 2

Variable			MEAN	MAX	MIN
	STD. DEV.		STD. ERROR		
ATEMP	19.0	26.0	14.0	9.899	7.000
WTEMP	10.1	12.0	8.2	2.687	1.900
PH	7.6	7.6	7.6	0.000	0.000
COND	1872.0	1959.0	1794.0	110.309	78.000
ALKA	332.5	339.0	326.0	9.192	6.500
DO	5.7	5.7	5.7	0.014	0.010
PSAT	57.0	65.0	49.0	11.314	8.000
ELEV	838.2	-	-	-	-

Site Name: Barker Dam

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	22.3	25.0	19.5	3.889	2.750
WTEMP	19.9	20.7	19.0	1.202	0.850
PH	8.2	9.5	6.8	1.909	1.350
COND	838.0	1205.0	471.0	519.016	367.000
ALKA	250.5	344.0	157.0	132.229	93.500
DO	4.4	8.4	0.4	5.607	3.965
PSAT	48.5	93.0	4.0	62.933	44.500
ELEV	1303.0	-	-	-	-

Site Name: Bolster Canyon Spring

Number of samples: 3

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	14.0	15.0	13.0	1.000	0.577
WTEMP	11.5	15.0	7.5	3.775	2.179
PH	7.7	8.0	7.5	0.265	0.153
COND	1879.3	2520.0	1318.0	604.914	349.247
ALKA	320.7	449.0	244.0	111.841	64.571
DO	4.5	7.5	2.0	2.754	1.590
PSAT	44.3	79.0	20.0	30.827	17.798
ELEV	829.0	-	-	-	-

Site Name: Buzzard Spring

Number of samples: 5

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	21.9	33.0	16.5	6.456	2.887
WTEMP	16.9	25.0	11.5	5.604	2.506
PH	7.8	8.2	7.4	0.354	0.158
COND	1550.0	1897.0	1354.0	260.805	116.636
ALKA	188.6	250.0	146.0	40.197	17.977
DO	6.4	7.2	5.2	0.871	0.390
PSAT	67.2	79.0	48.0	11.520	5.152
ELEV	612.6	-	-	-	-

Site Name: Chuckwalla Bill Spring

Number of samples: 3

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	23.5	27.0	20.0	3.500	2.021
WTEMP	21.5	24.0	17.5	3.500	2.021
PH	7.6	7.7	7.5	0.100	0.058
COND	863.7	938.0	773.0	83.704	48.326
ALKA	284.0	299.0	255.0	25.120	14.503
DO	4.6	6.3	3.3	1.517	0.876
PSAT	52.0	66.0	39.0	13.528	7.810
ELEV	853.4	-	-	-	-

Site Name: Cottonwood Spring

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	19.3	27.0	11.0	8.170	4.085
WTEMP	18.8	20.5	17.5	1.258	0.629
PH	7.4	8.3	6.9	0.638	0.319
COND	786.8	892.0	746.0	70.292	35.146
ALKA	218.8	221.0	215.0	2.630	1.315
DO	3.5	7.1	1.0	2.893	1.447
PSAT	36.5	71.0	11.0	29.456	14.728
ELEV	914.4	-	-	-	-

Site Name: Covington Tenaja

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	10.3	17.0	6.5	4.839	2.420
WTEMP	7.4	10.5	5.5	2.250	1.125
PH	7.8	8.2	7.3	0.370	0.185
COND	259.5	467.0	103.0	181.757	90.879
ALKA	35.0	61.0	18.0	19.305	9.652
DO	7.8	8.3	6.9	0.634	0.317
PSAT	73.8	84.0	64.0	8.421	4.211
ELEV	1584.9	-	-	-	-

Site Name: Cow Camp Dam

Number of samples: 3

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	18.2	24.5	11.0	6.788	3.919
WTEMP	14.5	19.5	7.5	6.229	3.596
PH	8.2	8.9	7.6	0.656	0.379
COND	807.7	1090.0	485.0	304.5	175.8
ALKA	232.0	280.0	186.0	47.032	27.154
DO	2.4	5.4	0.3	2.620	1.513
PSAT	25.3	58.0	2.0	29.143	16.826
ELEV	1255.7	-	-	-	-

Site Name: Fan Hill Canyon Headwater

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	15.3	20.0	10.5	6.718	4.750
WTEMP	9.0	10.5	7.5	2.121	1.500
PH	6.9	7.0	6.8	0.141	0.100
COND	775.5	810.0	714.0	48.790	34.500
ALKA	278.5	290.0	267.0	16.263	11.500
DO	3.0	3.1	2.8	0.233	0.165
PSAT	26.5	31.0	22.0	6.364	4.500
ELEV	1225.2	-	-	-	-

Site Name: Fortynine Palms Oasis

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	16.3	29.5	9.5	8.995	4.498
WTEMP	13.8	21.5	9.5	5.315	2.658
PH	7.3	7.8	6.8	0.480	0.240
COND	628.5	672.0	556.0	53.917	26.958
ALKA	201.5	244.0	176.0	30.784	15.392
DO	4.7	6.3	2.6	1.584	0.792
PSAT	46.0	59.0	30.0	14.259	7.130
ELEV	853.4	-	-	-	-

Site Name: Fortynine Palms Tank

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	10.0	-	-	-	-
WTEMP	16.5	-	-	-	-
PH	7.5	-	-	-	-
COND	620.0	-	-	-	-
ALKA	219.0	-	-	-	-
DO	5.5	-	-	-	-
PSAT	43.0	-	-	-	-
ELEV	911.3	-	-	-	-

Site Name: Garret Canyon

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	14.9	30.0	7.5	10.347	5.174
WTEMP	10.8	16.0	7.5	3.663	1.831
PH	7.6	8.0	7.3	0.294	0.147
COND	801.8	871.0	686.0	80.259	40.130
ALKA	317.0	330.0	307.0	10.231	5.115
DO	5.4	6.2	4.3	0.913	0.457
PSAT	49.0	55.0	42.0	6.976	3.488
ELEV	1237.4	-	-	-	-

Site Name: Howard Well

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	17.0	-	-	-	-
WTEMP	11.0	-	-	-	-
PH	7.3	-	-	-	-
COND	572.0	-	-	-	-
ALKA	217.0	-	-	-	-
DO	2.0	-	-	-	-
PSAT	17.0	-	-	-	-
ELEV	1167.3	-	-	-	-

Site Name: Long Canyon Shortcut Spring

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	17.3	20.0	14.5	3.889	2.750
WTEMP	13.4	17.0	9.8	5.091	3.600
PH	7.4	7.5	7.2	0.212	0.150
COND	732.0	877.0	587.0	205.061	145.000
ALKA	268.0	273.0	263.0	7.071	5.000
DO	6.2	8.0	4.4	2.546	1.800
PSAT	24.5	38.0	11.0	19.092	13.500
ELEV	914.4	-	-	-	-

Site Name: Lost Palms Canyon Tunnel

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	20.0	26.0	14.0	8.485	6.000
WTEMP	15.0	15.0	15.0	0.000	0.000
PH	8.0	8.0	7.9	0.071	0.050
COND	616.0	655.0	577.0	55.154	39.000
ALKA	233.5	247.0	220.0	19.092	13.500
DO	4.5	5.2	3.8	1.047	0.740
PSAT	47.0	55.0	39.0	25.695	8.000
ELEV	822.9	-	-	-	-

Site Name: Lost Palms Oasis

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	19.0	26.5	11.5	10.607	7.500
WTEMP	17.6	23.7	11.5	8.627	6.100
PH	7.3	7.3	7.3	0.000	0.000
COND	767.0	778.0	756.0	15.556	11.000
ALKA	251.0	262.0	240.0	15.556	11.000
DO	3.5	4.4	2.7	1.216	0.860
PSAT	37.5	51.0	24.0	19.092	13.500
ELEV	949.4	-	-	-	-

Site Name: Meek Seep

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	21.5	-	-	-	-
WTEMP	10.5	-	-	-	-
PH	7.5	-	-	-	-
COND	674.0	-	-	-	-
ALKA	255.0	-	-	-	-
DO	8.2	-	-	-	-
PSAT	73.0	-	-	-	-
ELEV	694.9	-	-	-	-

Site Name: Munsen Canyon #1

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	22.0	-	-	-	-
WTEMP	17.0	-	-	-	-
PH	7.3	-	-	-	-
COND	496.0	-	-	-	-
ALKA	166.0	-	-	-	-
DO	7.6	-	-	-	-
PSAT	58.0	-	-	-	-
ELEV	966.2	-	-	-	-

Site Name: Munsen Canyon #2

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	18.0	-	-	-	-
WTEMP	11.6	-	-	-	-
PH	7.3	-	-	-	-
COND	805.0	-	-	-	-
ALKA	236.0	-	-	-	-
DO	5.7	-	-	-	-
PSAT	52.0	-	-	-	-
ELEV	1060.7	-	-	-	-

Site Name: Munsen Canyon #3

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	20.0	-	-	-	-
WTEMP	12.8	-	-	-	-
PH	6.9	-	-	-	-
COND	514.0	-	-	-	-
ALKA	168.0	-	-	-	-
DO	3.2	-	-	-	-
PSAT	30.0	-	-	-	-
ELEV	1057.6	-	-	-	-

Site Name: Owl Tank

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	14.5	-	-	-	-
WTEMP	12.5	-	-	-	-
PH	6.9	-	-	-	-
COND	558.0	-	-	-	-
ALKA	189.0	-	-	-	-
DO	2.1	-	-	-	-
PSAT	21.0	-	-	-	-
ELEV	1021.0	-	-	-	-

Site Name: Pearl Spring

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	16.5	21.5	11.5	7.071	5.000
WTEMP	16.2	19.3	13.0	4.455	3.150
PH	7.0	7.0	7.0	0.000	0.000
COND	705.0	710.0	700.0	7.071	5.000
ALKA	278.5	285.0	272.0	9.192	6.500
DO	2.0	3.0	1.0	1.407	0.995
PSAT	19.0	28.0	10.0	12.728	9.000
ELEV	1318.2	-	-	-	-

Site Name: Pine Spring

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	13.0	-	-	-	-
WTEMP	13.0	-	-	-	-
PH	7.1	-	-	-	-
COND	679.0	-	-	-	-
ALKA	209.0	-	-	-	-
DO	4.5	-	-	-	-
PSAT	51.0	-	-	-	-
ELEV	1286.2	-	-	-	-

Site Name: Rattlesnake Canyon Potholes

Number of samples: 7

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	12.5	17.0	8.5	4.143	2.072
WTEMP	9.8	14.0	5.0	4.031	2.016
PH	9.4	10.0	8.8	0.693	0.346
COND	358.0	516.0	273.0	111.406	55.703
ALKA	51.5	98.0	19.0	37.987	18.993
DO	8.2	10.0	6.6	1.476	0.738
PSAT	71.0	92.0	52.0	18.294	9.147
ELEV	944.8	-	-	-	-

Site Name: Rattlesnake Canyon Potholes B

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	12.5	17.0	8.5	4.143	2.072
WTEMP	9.8	14.0	5.0	4.031	2.016
PH	9.4	10.0	8.8	0.693	0.346
COND	358.0	516.0	273.0	111.406	55.703
ALKA	51.5	98.0	19.0	37.987	18.993
DO	8.2	10.0	6.6	1.476	0.738
PSAT	71.0	92.0	52.0	18.294	9.147
ELEV	944.8	-	-	-	-

Site Name: Rattlesnake Canyon Potholes C

Number of samples: 9

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	15.0	31.5	8.5	7.115	2.372
WTEMP	12.3	23.5	7.5	5.026	1.675
PH	8.6	9.9	7.0	1.038	0.346
COND	276.2	489.0	179.0	98.263	32.754
ALKA	65.3	104.0	14.0	27.092	9.031
DO	6.8	8.6	3.2	1.578	0.526
PSAT	62.3	95.0	38.0	16.793	5.598
ELEV	944.8	-	-	-	-

Site Name: Rattlesnake Canyon Potholes D

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	13.6	17.0	10.0	3.902	1.951
WTEMP	11.5	14.0	8.5	2.915	1.458
PH	8.7	9.5	8.0	0.618	0.309
COND	238.8	286.0	180.0	44.612	22.306
ALKA	64.3	74.0	50.0	11.442	5.721
DO	6.5	7.9	5.0	1.193	0.596
PSAT	50.6	63.0	39.5	9.759	4.879
ELEV	944.8	-	-	-	-

Site Name: Rattlesnake Canyon Potholes E

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	14.5	15.0	14.0	0.577	0.289
WTEMP	10.0	12.0	7.0	2.449	1.225
PH	8.8	9.7	7.0	1.234	0.617
COND	298.0	418.0	214.0	92.740	46.370
ALKA	73.5	116.0	9.1	49.987	24.994
DO	8.9	13.2	6.8	2.972	1.486
PSAT	85.3	106.0	62.0	19.033	9.516
ELEV	944.8	-	-	-	-

Site Name: Rattlesnake Spring

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	18.8	20.5	17.0	2.475	1.750
WTEMP	15.8	16.0	15.5	0.354	0.250
PH	7.3	7.3	7.2	0.071	0.050
COND	1105.5	1223.0	988.0	166.170	117.500
ALKA	359.5	373.0	346.0	19.092	13.500
DO	3.1	3.4	2.7	0.495	0.350
PSAT	30.5	34.0	27.0	4.950	3.500
ELEV	1080.5	-	-	-	-

Site Name: Shady Pool Tank

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	17.0	19.0	15.0	2.828	2.000
WTEMP	10.8	11.0	10.5	0.354	0.250
PH	7.5	7.6	7.6	0.141	0.100
COND	359.0	367.0	351.0	11.314	8.000
ALKA	106.0	125.0	87.0	26.870	19.000
DO	5.5	7.2	3.7	2.468	1.745
PSAT	50.0	66.0	34.0	22.627	16.000
ELEV	960.1	-	-	-	-

Site Name: Smithwater Falls Spring

Number of samples: 3

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	20.8	26.0	11.5	8.098	4.676
WTEMP	15.0	21.0	10.5	5.408	3.122
PH	7.7	8.4	7.3	0.586	0.338
COND	918.7	1059.0	744.0	160.282	92.539
ALKA	249.3	263.0	233.0	15.177	8.762
DO	4.3	5.5	2.0	2.015	1.163
PSAT	41.3	53.0	22.0	16.862	9.735
ELEV	1286.2	-	-	-	-

Site Name: Stubbe Spring Lower

Number of samples: 4

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	9.4	13.0	6.0	3.038	1.519
WTEMP	6.0	7.5	4.5	1.472	0.736
PH	7.7	8.2	7.3	0.403	0.202
COND	743.3	786.0	663.0	57.308	28.654
ALKA	302.3	316.0	290.0	10.844	5.422
DO	5.6	10.2	3.2	3.173	1.587
PSAT	40.8	63.0	26.0	16.721	8.360
ELEV	1345.3	-	-	-	-

Site Name: Stubbe Spring Middle

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	19.5	-	-	-	-
WTEMP	13.5	-	-	-	-
PH	7.3	-	-	-	-
COND	759.0	-	-	-	-
ALKA	283.0	-	-	-	-
DO	6.0	-	-	-	-
PSAT	58.0	-	-	-	-
ELEV	1356.3	-	-	-	-

Site Name: Summit Spring

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	19.5	-	-	-	-
WTEMP	16.5	-	-	-	-
PH	7.2	-	-	-	-
COND	785.0	-	-	-	-
ALKA	237.0	-	-	-	-
DO	2.2	-	-	-	-
PSAT	24.0	-	-	-	-
ELEV	807.7	-	-	-	-

Site Name: Upper Burns Spring

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	12.7	19.8	5.5	10.112	7.150
WTEMP	8.9	12.3	5.5	4.808	3.400
PH	6.9	6.9	6.8	0.071	0.050
COND	775.5	820.0	731.0	62.933	44.500
ALKA	313.0	339.0	287.0	36.770	26.000
DO	6.8	10.2	3.5	4.773	3.375
PSAT	54.0	83.0	25.0	41.012	29.000
ELEV	1508.7	-	-	-	-

Site Name: West Drainage Potholes

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	12.0	-	-	-	-
WTEMP	11.5	-	-	-	-
PH	7.3	-	-	-	-
COND	1141.0	-	-	-	-
ALKA	308.0	-	-	-	-
DO	3.3	-	-	-	-
PSAT	29.0	-	-	-	-
ELEV	1194.8	-	-	-	-

Site Name: Wood Spring

Number of samples: 5

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	16.8	28.5	9.5	9.378	4.194
WTEMP	15.7	27.0	10.0	6.815	3.048
PH	7.2	7.7	6.9	0.344	0.154
COND	856.6	933.0	793.0	51.384	22.980
ALKA	292.6	322.0	258.0	23.234	10.390
DO	1.6	2.4	1.0	0.511	0.229
PSAT	14.6	21.0	9.0	4.393	1.965
ELEV	899.1	-	-	-	-

Appendix II. Mean (MEAN), maximum (MAX), minimum (MIN), standard deviation (STD. DEV.), and standard error of the mean (STD. ERROR) for eight chemical/physical variables measured at 37 sites in Joshua Tree National Park. The sites are grouped into six habitat categories: natural tanks, developed tanks, developed springs, wells, natural springs, and reservoirs. Acronyms and units for the variables are the same as Appendix I.

Site Name: Natural Tank

Number of samples: 42

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	14.9	33.0	6.5	6.157	0.950
WTEMP	11.8	25.0	5.0	4.844	0.747
PH	8.3	10.0	6.7	0.977	0.151
COND	499.1	1897.0	103.0	445.103	68.681
ALKA	99.2	308.0	9.1	78.048	12.043
DO	6.5	13.2	2.1	2.073	0.320
PSAT	60.2	106.0	21.0	20.033	3.091
ELEV	986.6	1584.9	612.6	239.104	36.895

Site Name: Developed Tank

Number of samples: 2

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	17.0	19.0	15.0	2.828	2.000
WTEMP	10.8	11.0	10.5	0.354	0.250
PH	7.5	7.6	7.4	0.141	0.100
COND	359.0	367.0	351.0	11.314	8.000
ALKA	106.0	125.0	87.0	26.870	19.000
DO	5.5	7.2	3.7	2.468	1.745
PSAT	50.0	66.0	34.0	22.627	16.000
ELEV	960.1	960.1	960.1	-	-

Site Name: Developed Spring

Number of samples: 20

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	18.7	28.5	9.5	6.646	1.486
WTEMP	16.9	27.0	10.0	4.336	0.969
PH	7.3	8.3	6.9	0.407	0.091
COND	815.6	1223.0	577.0	141.952	31.742
ALKA	271.3	373.0	209.0	46.221	10.335
DO	3.3	7.1	1.0	1.922	0.430
PSAT	33.9	71.0	9.0	20.412	4.564
ELEV	989.9	1356.3	822.9	182.048	40.707

Site Name: Well

Number of samples: 1

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	17.0	-	-	-	-
WTEMP	11.0	-	-	-	-
PH	7.3	-	-	-	-
COND	572.0	-	-	-	-
ALKA	217.0	-	-	-	-
DO	2.0	-	-	-	-
PSAT	17.0	-	-	-	-
ELEV	1167.3	-	-	-	-

Site Name: Natural Spring

Number of samples: 31

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	16.2	30.0	5.5	7.009	1.259
WTEMP	11.9	23.7	4.5	4.763	0.856
PH	7.5	8.4	6.8	0.389	0.070
COND	924.4	2520.0	496.0	467.944	84.045
ALKA	270.5	449.0	166.0	59.830	10.746
DO	5.2	10.2	2.0	2.166	0.389
PSAT	44.6	83.0	11.0	18.121	3.255
ELEV	1067.7	1508.7	694.9	238.587	42.852

Site Name: Reservoir

Number of samples: 5

Variable	MEAN	MAX	MIN	STD. DEV.	STD. ERROR
ATEMP	19.8	25.0	11.0	5.641	2.523
WTEMP	16.6	20.7	7.5	5.335	2.386
PH	8.2	9.5	6.8	1.062	0.475
COND	819.8	1205.0	471.0	337.615	150.986
ALKA	239.4	344.0	157.0	74.698	33.406
DO	3.2	8.4	0.3	3.528	1.578
PSAT	34.6	93.0	2.0	39.696	17.753
ELEV	1274.6	1303.0	1255.7	25.880	11.574

Appendix III. Cluster assignments for 101 samples obtained from 37 aquatic ecosystems in Joshua Tree National Park. Sample acronyms correspond to site names listed in Table 1, and the numbers following the acronyms designate the sample number.

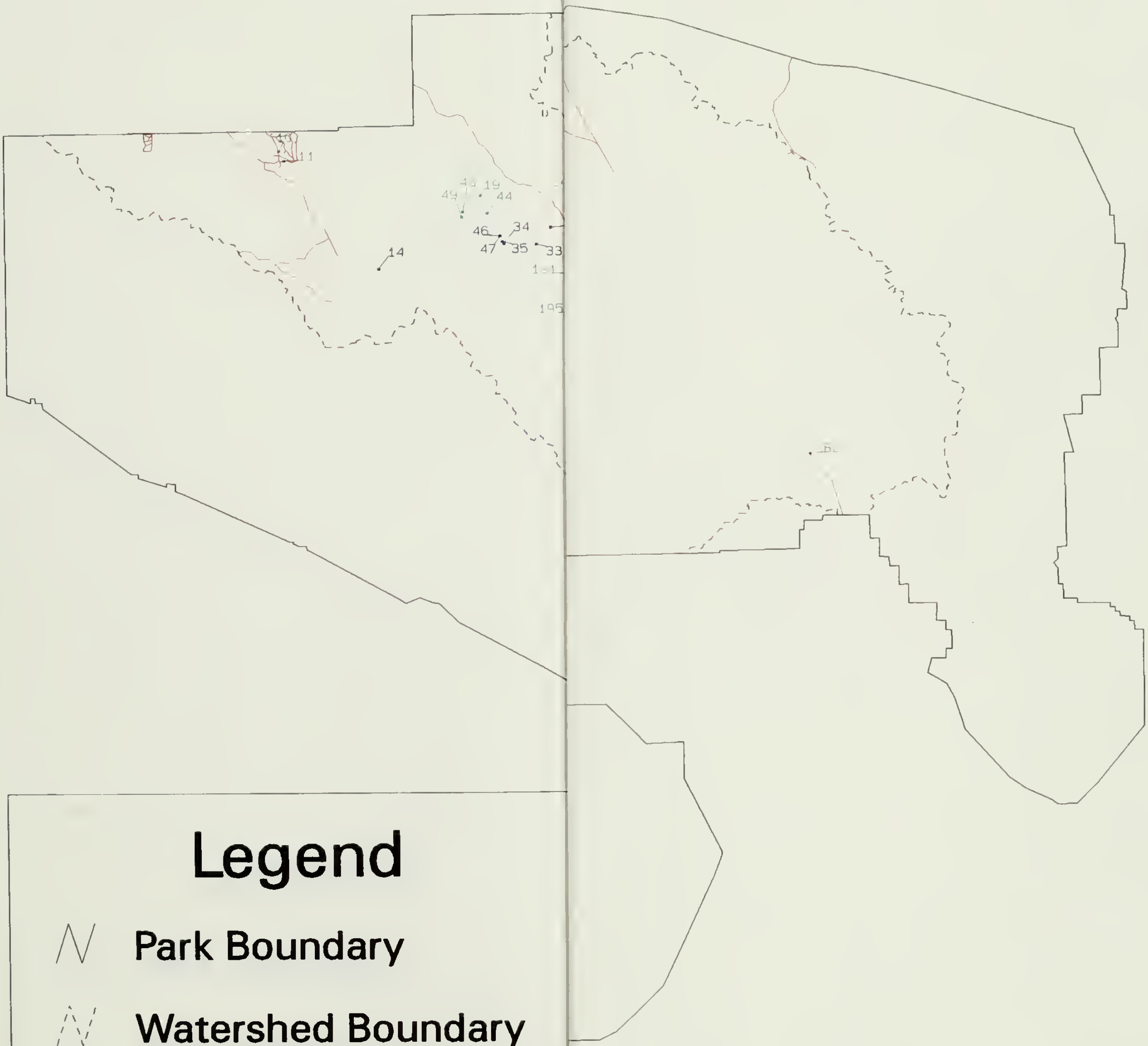
Cluster	Number of Samples	Assignment			
1	31	BADA-2	FPOA-2	FPOA-3	LPCT-2
		RSPO-1	RSPO-2	RSPO-4	RSPO-5
		RSPO-6	RSPO-7	RSPB-1	RSPB-2
		RSPB-3	RSPB-4	RSPC-1	RSPC-3
		RSPC-4	RSPC-5	RSPC-6	RSPC-7
		RSPC-8	RSPC-9	RSPD-1	RSPD-2
		RSPD-3	RSPD-4	RSPE-1	RSPE-2
		RSPE-3	RSPE-4	SPTA-2	
2	34	BADA-1	COSP-1	COSP-4	CCDA-1
		CCDA-2	FPOA-4	FPTA	GACA-2
		GACA-3	GACA-4	HOWE	LOPA-1
		MUC2	MUC3	OWTA	PESP-1
		PESP-2	PISP	RASP-1	RASP-2
		SPTA-1	SFSP-2	SSPM	SSPL-1
		SSPL-2	SSPL-4	FAHE-1	FAHE-2
		LCSP-2	UBSP-1	WDPO	WOSP-1
		WOSP-4	WOSP-5		
3	19	CBSP-1	CBSP-2	CBSP-3	COSP-2
		COSP-3	CCDA-3	FPOA-1	GACA-1
		LPCT-1	LOPA-2	MUC1	RSPO-3
		RSPC-2	SFSP-1	SFSP-3	SMSP
		LCSP-1	WOSP-2	WOSP-3	

Appendix III. (continued)

Cluster	Number of Samples	Assignment			
4	6	COTE-1	COTE-2	COTE-3	COTE-4
		SSPL-3	UBSP-2		
5	11	BUSP-1	BUSP-2	BUSP-3	BUSP-4
		BUSP-5	MESE	BASP-1	BASP-2
		BOSP-1	BOSP-2	BOSP-3	

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their developement is in the best interest of all our people. The department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS D-319 April 1998



Legend

/\/ **Park Boundary**

/\/ **Watershed Boundary**

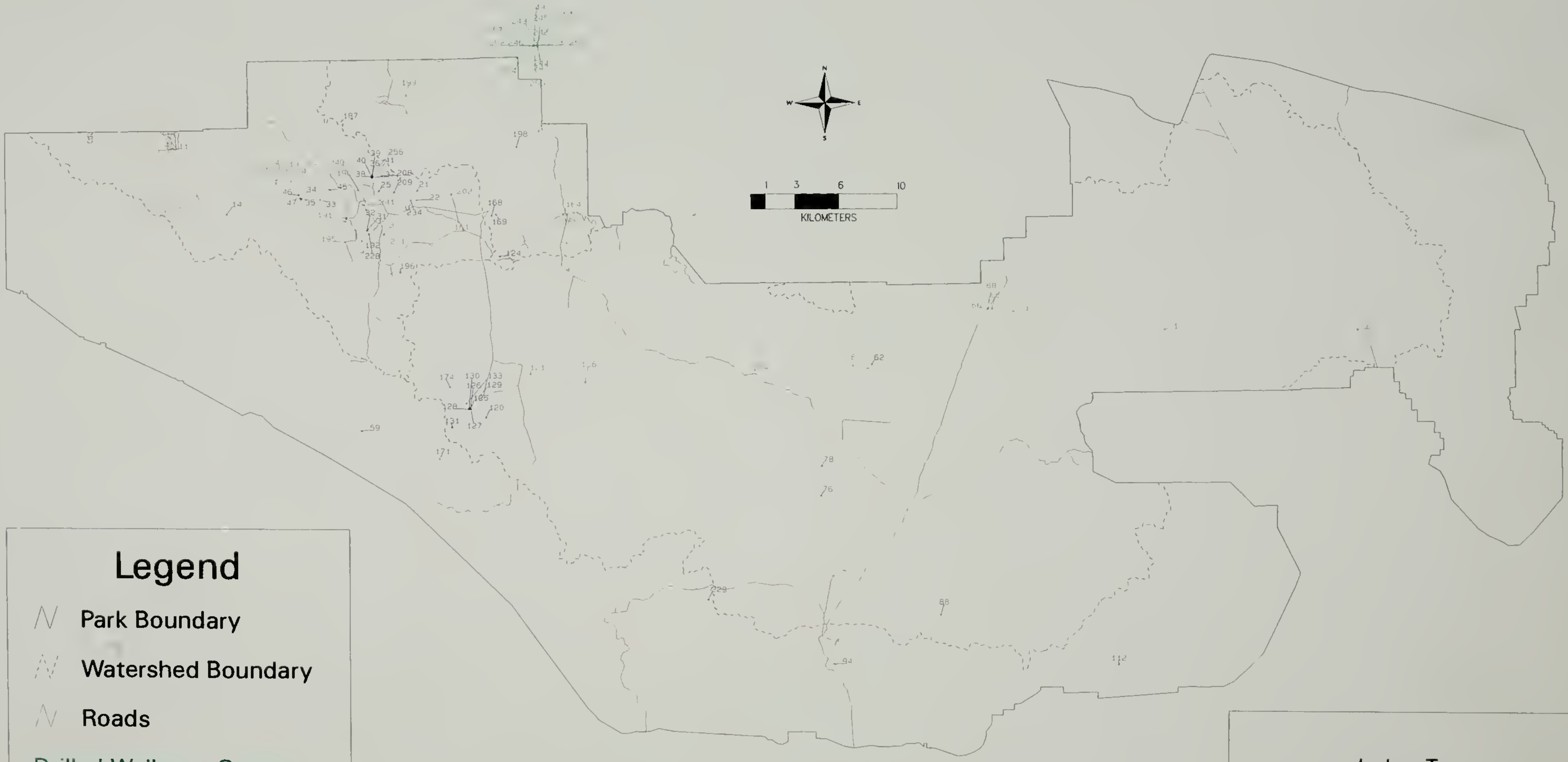
/\/ **Roads**

Drilled Wells are Green

Dug Wells are Blue

Joshua Tree
National Park
Water Resources

WELLS



Legend

/\/ Park Boundary

/\/ Watershed Boundary

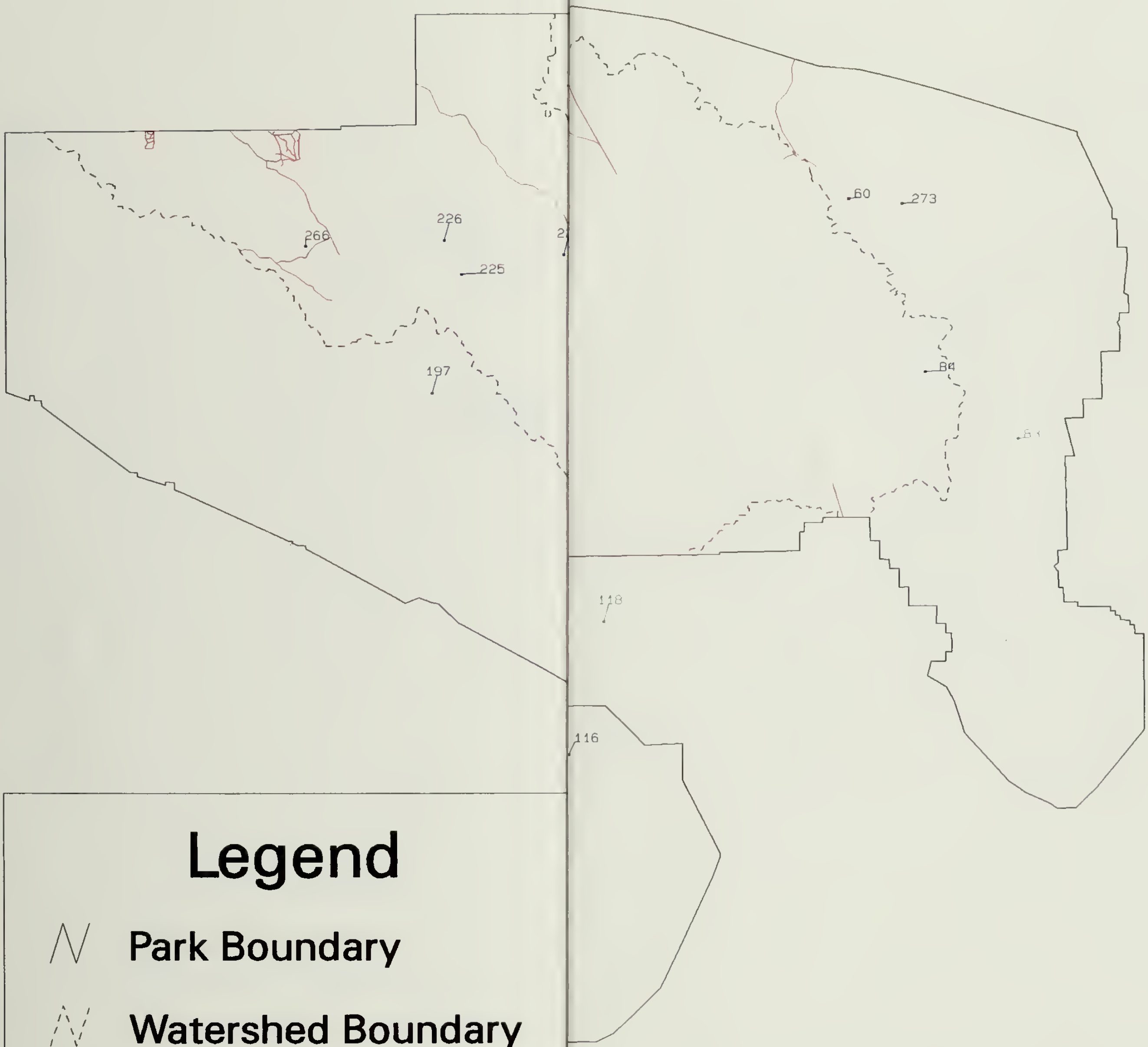
/\/ Roads

Drilled Wells are Green

Dug Wells are Blue

Joshua Tree
National Park
Water Resources

WELLS



Legend

Park Boundary

Watershed Boundary

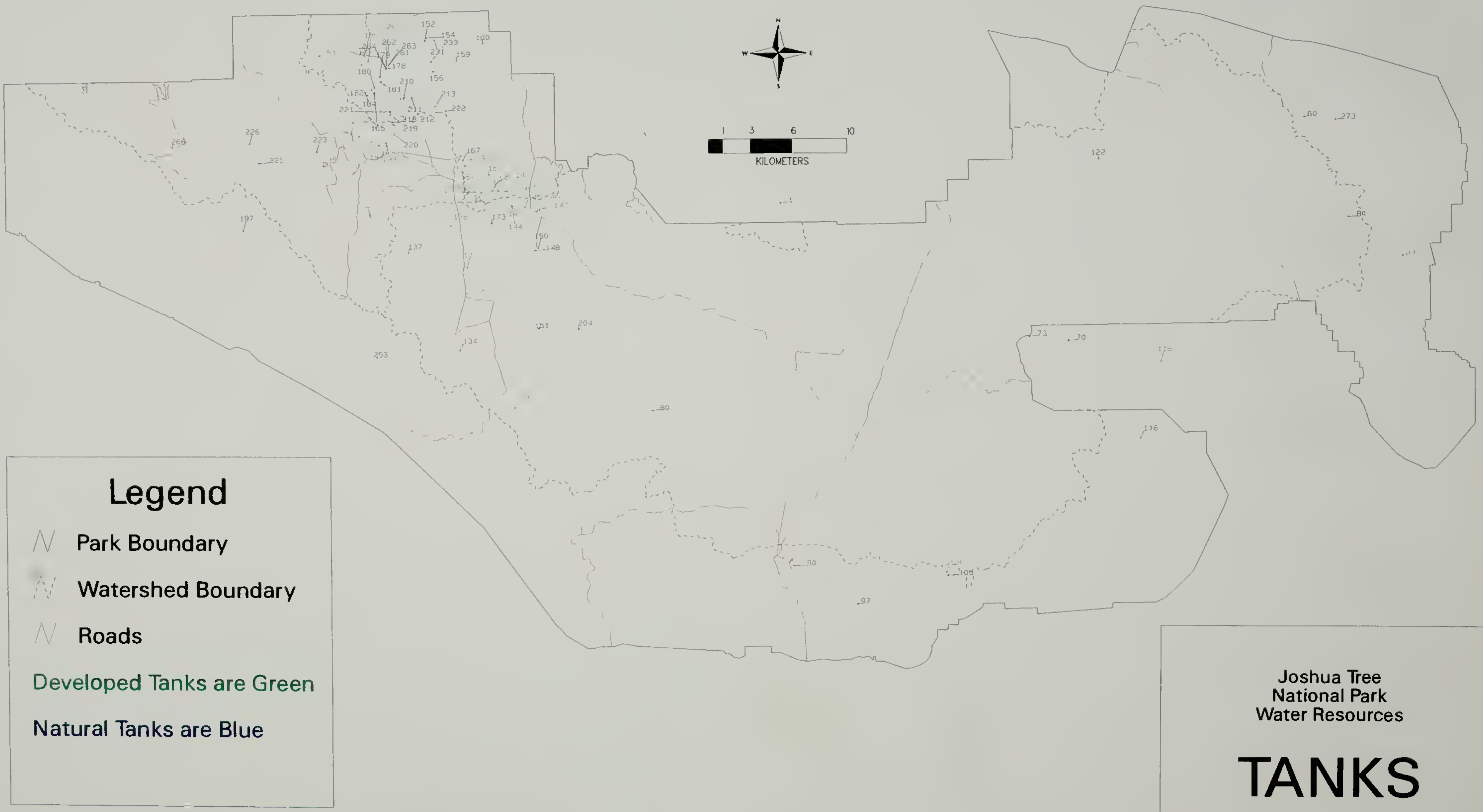
Roads

Developed Tanks are Green

Natural Tanks are Blue

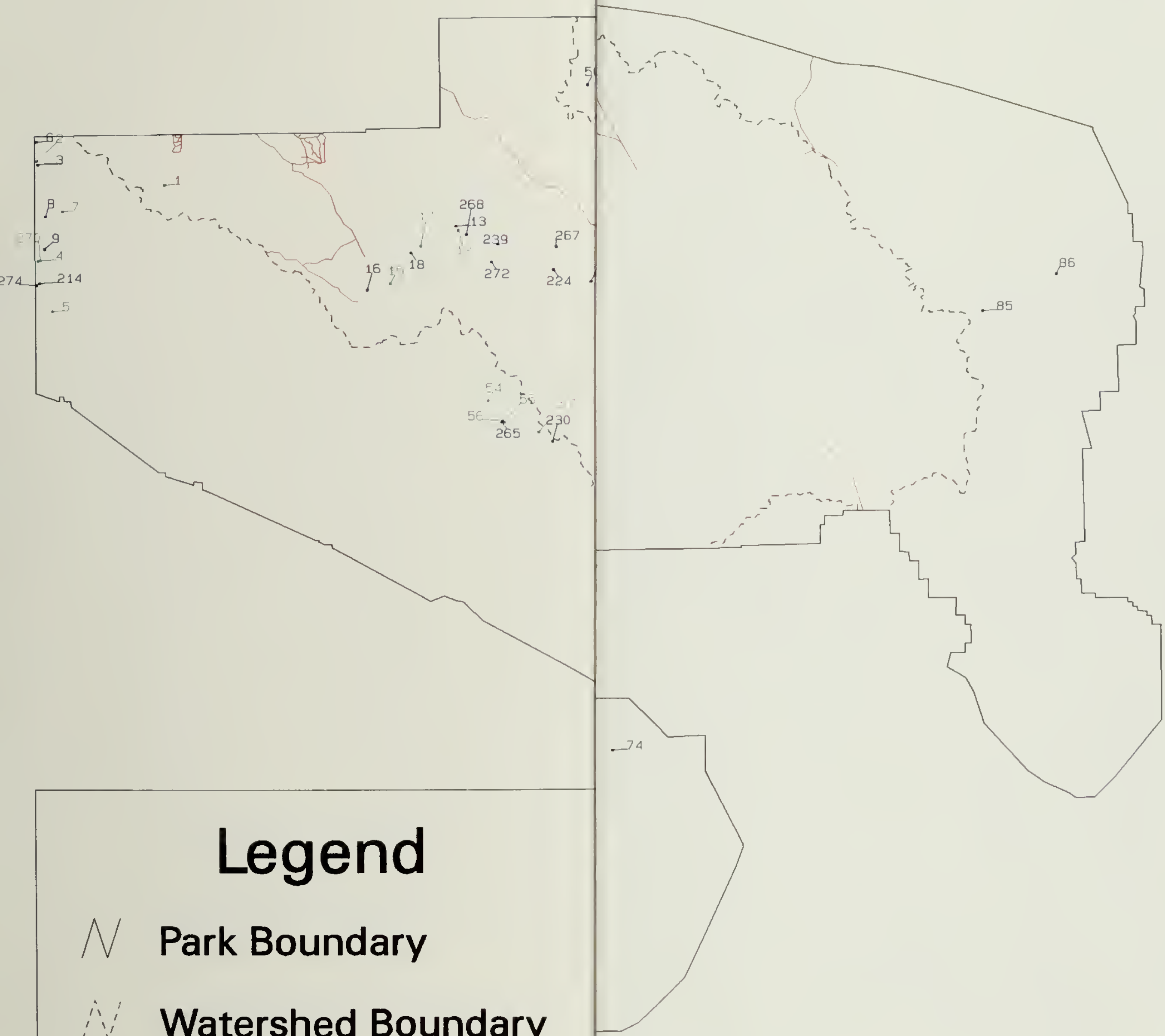
Joshua Tree
National Park
Water Resources

TANKS



Joshua Tree
National Park
Water Resources

TANKS



Legend

Park Boundary

Watershed Boundary

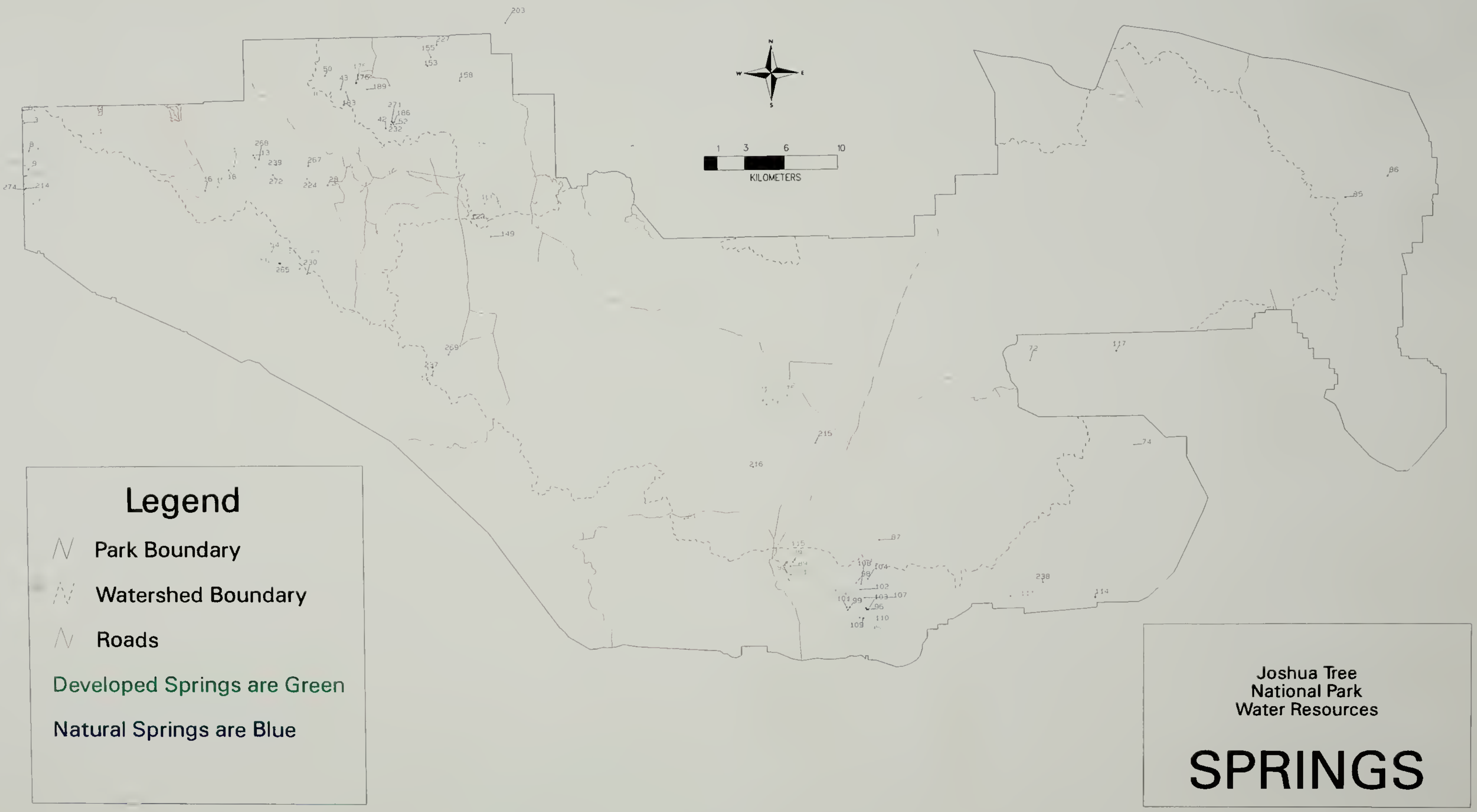
Roads

Developed Springs are Gree

Natural Springs are Blue

Joshua Tree
National Park
Water Resources

SPRINGS



Legend

Park Boundary

Watershed Boundary

Roads

Developed Springs are Green

Natural Springs are Blue

Joshua Tree
National Park
Water Resources

SPRINGS